National Conservation Strategy for Cultus Lake Sockeye Salmon (*Oncorhynchus Nerka*)

Cultus Sockeye Recovery Team

Fisheries and Oceans Canada
Science Branch, Pacific Region
Cooperative Resource Management Institute
School of Resource and Environmental Management
Simon Fraser University
Burnaby, B.C. V5A 1S6

2009

Canadian Technical Report of
Fisheries and Aquatic Sciences 2846

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 456 in this series were issued as Technical reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des
sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon regional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2846

2009

NATIONAL CONSERVATION STRATEGY FOR CULTUS LAKE SOCKEYE SALMON (*Oncorhynchus nerka*)

by

Cultus Sockeye Recovery Team

Fisheries and Oceans Canada
Science Branch, Pacific Region
Cooperative Resource Management Institute
School of Resource and Environmental Management
Simon Fraser University
Burnaby, B.C. V5A 1S6

© Her Majesty the Queen in Right of Canada 2009
Cat. No. Fs 97-6/2846E ISSN 0706-6457

Correct citation for this publication:

Cultus Sockeye Recovery Team. 2009. National conservation strategy for Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 2846: viii + 46 p.

TABLE OF CONTENTS

Page

LIST OF FIGURES v

LIST OF TABLES v

LIST OF ANNEXES vi

ABSTRACT vii

EXECUTIVE SUMMARY 1
COSEWIC Species Information 2

BACKGROUND 3
Distribution 3
Freshwater distribution 3
Ocean distribution 3
Distribution trends 3
Population Structure 4
Trends in population structure 5
Population Abundance 5
Trends in population abundance 5
Biological Limiting Factors 7
Co-migration 7
Migration timing 7
Migration route 7
Freshwater productivity 7
Spawning behaviour 7
Fry behaviour 7
Threats to Population Viability 8
Natural threats 8
Human-induced threats 10
Habitat Identification 14
General habitat requirements 14
Important habitat 15
Habitat trends 18
Habitat protection 19
Ecological Role 19
Importance to People 19
Knowledge Gaps 20
Early migration 20
Timing and productivity 20
Habitat requirements and impacts 20
Predators and parasites 21
Genetic trends 21
Marine distribution 21

BIOLOGICAL AND TECHNICAL FEASIBILITY 22
Biological Feasibility 22
Technical Feasibility 22
Recommended Scale for Conservation 23

CONSERVATION AND REBUILDING 24
Conservation Goal 24
Conservation Objectives 24
Objective 1 25
Objective 2 25
Objective 3 25
Objective 4 26
Approaches to Meeting Conservation Objectives 26
Control of exploitation 26
Maximizing freshwater survival 26
Maintaining assessments over the long term 28
Fish culture 28
Community awareness 29
Potential Impacts of the Conservation Strategy on Other Species 29
Actions Already Complete or Underway 29
Population assessment 29
Fish culture 30
Early migration/high mortality 30
Aquifer assessment 30
Assessment of littoral habitat 30
Impact of pikeminnow predation 30
Marine survival and timing 31
Control of exploitation 31
Community awareness 33
Evaluation 33

LITERATURE CITED 34

LIST OF FIGURES

Figure **Page**

1. Freshwater migration route for Cultus sockeye 3
2. DFO technicians sampling Cultus sockeye near Lindell Beach, 1995 4
3. Trend in number of successful spawners in the Cultus sockeye salmon population 6
4. Migration timing of the major Fraser sockeye groups. Cultus belong to the "late" run 6
5. Northern pikeminnow caught during Cultus Lake Pikeminnow Derby, 2003 10
6. Fraser sockeye at dockside in Steveston, 1946 11
7. Cultus sockeye population sizes 11
8. Soowahlie Church on Sweltzer Creek, ca. 1890 12
9. The north end of Cultus Lake, with Sweltzer Creek draining to the left. The cluster of buildings near the bottom left is the DFO Cultus Lake Laboratory 13
10. Private docks extend from Lindell Beach 13
11. Aerial vies of Cultus Lake. The developed north end is at bottom right 15
12. Silt washed into migratory habitat in Sweltzer Creek, 2004 16
13. Disturbance of migratory habitat near the counting fence, 2002 17
14. The main spawning beaches used by Cultus sockeye 18
15. First Nations fishing vessel in the lower Fraser 20

LIST OF TABLES

Table **Page**

1. Summary of threats to the Cultus sockeye population, by life stage 9
2. Summary of approaches to the conservation of the Cultus sockeye population 27
3. Summary of enhancement results, captive breeding and supplementation projects 31

LIST OF ANNEXES

Annex **Page**

1. Freshwater productivity 38
2. Target levels of abundance for Objective 4 40
3. The Cultus sockeye captive breeding project 43
4. Cultus Sockeye Recovery Team membership 44
5. Record of cooperation and consultation 45

LIST OF ANNEX FIGURES

Figure **Page**

1. Relation between smolts/spawner and spawners for Cultus sockeye 38
2. Time series of the 4 cycle lines of Cultus sockeye salmon, labeled in the text as the 1999-2003 cycle lines 39
3. Population increase/decline of Cultus Lake sockeye salmon over three generations (12 years) 42

ABSTRACT

Cultus Sockeye Recovery Team. 2009. National conservation strategy for Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 2846: viii + 46 p.

The abundance of all life stages of Cultus sockeye has declined significantly in recent decades. As a result of this decline, the population was designated by the Committee on the Status of Endangered Wildlife in Canada as *Endangered* in 2002. In response to that designation, and in anticipation of the proclamation of the *Species at Risk Act* (*SARA*), Fisheries and Oceans Canada formed the Cultus Sockeye Recovery Team, which produced a recovery strategy in 2005. When the decision not to list the population on Schedule 1 of *SARA* was announced, the recovery strategy was re-profiled as this conservation strategy.

The conservation strategy describes the status and trends in the distribution and abundance of the population, biological limiting factors and threats to the viability of the population. Specific habitats that are important to the population's survival and recovery are identified: the migratory corridor of Sweltzer Creek; the lake bed and its associated aquifers at depths from 1 to 20 m at six locations; and the pelagic zone of Cultus Lake.

The conservation goal identifies the need to halt the population's decline and recover it to the status of a wild, viable, genetically robust population capable of supporting ecosystem functions as well as sustainable use. The goal is to be achieved through four sequential objectives that are intended to: 1) secure genetic variability; 2) ensure the population growth; 3) result in de-listing from *Endangered* to *Not at Risk*; and 4) facilitate the selection of conservation benchmarks based on our current understanding of the dynamics of the population.

Approaches to meet the conservation objectives include the control of fisheries harvest, predator control and the removal of Eurasian watermilfoil to increase freshwater survival, fish culture and captive breeding, and promoting community awareness. The strategy concludes with a summary of the status of the conservation approaches that are underway.

RÉSUMÉ

Cultus Sockeye Recovery Team. 2009. National conservation strategy for Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 2846: viii + 46 p.

L'abondance de saumons rouges du lac Cultus à tous les stades de leur développement a beaucoup diminué au cours des dernières décennies. À la suite de ce déclin, le Comité sur la situation des espèces en péril au Canada a désigné cette population « en voie de disparition » en 2002. Compte tenu de cette désignation, et dans la perspective de la proclamation de la *Loi sur les espèces en péril (LEP)*, Pêches et Océans Canada a mis sur pied l'Équipe de rétablissement du saumon rouge du lac Cultus, qui a élaboré une stratégie de rétablissement en 2005. Lorsque la décision de ne pas inscrire la population sur la liste de l'annexe 1 de la *LEP* a été annoncée, la stratégie de rétablissement est devenue une stratégie de conservation.

La stratégie de conservation décrit l'état et les tendances concernant la répartition et l'abondance de la population, les facteurs biologiques limitatifs et les menaces pour la viabilité de la population. Les habitats spécifiques qui sont importants pour la survie et le rétablissement de la population ont été déterminés : le corridor migratoire du ruisseau Sweltzer; le lit du lac et les aquifères qui y sont associés à des profondeurs de 1 m à 20 m, à six emplacements, et la zone pélagique du lac Cultus.

L'objectif de conservation vise à stopper le déclin de la population et à ramener celle-ci à l'état de population sauvage, viable et génétiquement robuste qui soit capable de soutenir les fonctions de l'écosystème, ainsi que d'être soumise à une exploitation durable. On prévoit atteindre cet objectif au moyen de quatre autres objectifs séquentiels, qui viseront à : 1) assurer la viabilité génétique; 2) assurer la croissance de la population; 3) faire passer la désignation de « en voie de disparition » à « non en péril »; 4) faciliter la sélection de points de repère en matière de conservation basés sur notre compréhension actuelle de la dynamique de la population.

Les approches utilisées pour atteindre l'objectif de conservation comprennent le contrôle des captures, le contrôle des prédateurs et l'élimination du myriophylle en épi, dans le but de favoriser la survie en eau douce, la pisciculture et l'élevage en captivité, ainsi que de sensibiliser les collectivités. La stratégie se termine par un résumé concernant l'état des méthodes de conservations qui sont en cours.

Fisheries and Oceans Canada
Pêches et Océans Canada
Canada

National Conservation Strategy for the

Cultus Lake Sockeye Salmon

[*Oncorhynchus nerka*]

EXECUTIVE SUMMARY

"This Conservation Strategy first considers the population's status and the main threats to its viability, then proposes specific conservation goals, objectives and actions."

The Cultus population of sockeye salmon is unique and endangered. This Conservation Strategy first considers its status and the main threats to its viability, then proposes specific conservation goals, objectives and approaches.

Cultus Lake is in the traditional territory of the Soowahlie Indian Band near the town of Chilliwack in the upper Fraser Valley. Its sockeye population has been monitored longer than any other in B.C. Cultus sockeye belongs to the late run – the latest-spawning of the four groups of Fraser sockeye. Adults enter the lake by way of the Fraser, Sumas, Vedder and Chilliwack rivers, finally connecting with the lake through Sweltzer Creek. They spawn on gravel beaches around the lake.

The abundance of all life stages of Cultus sockeye has declined significantly in recent decades. The most recent estimates are among the lowest recorded for the population. From historic abundances greater than 70,000 spawners, the population has declined to the point where the return for 2004 was less than 100 fish, and there is evidence that irreplaceable genetic diversity is being lost.

As a result of this continuous decline, Cultus sockeye was designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as *Endangered* in 2002. What has caused the decline, and how can it be reversed? Although there is evidence that watermilfoil, stream channelization and foreshore development may interfere with prime spawning sites, freshwater habitat degradation is not the main cause of the population's recent decline. Instead, there are three main causes:

- Over-exploitation in mixed-stock fisheries before 1995;
- Poor marine survival in the early to mid 1990s; and
- Since 1995, high pre-spawn mortality caused by unusually early migrations into freshwater and an associated parasite infection.

Unfortunately, none of these causes work in isolation. For example, reductions in exploitation rates as long ago as 1998 have been confounded by higher than normal pre-spawning mortality. And there are other threats: emigrating smolts and returning adults run a gauntlet of industrial and residential development in the Fraser Valley; adults must pass through Sweltzer Creek at a time of heavy recreational use and high water temperatures; and freshwater survival is lower than normal, possibly due to predation.

The Recovery Team identified the habitat it believes is important to the population's survival and recovery. We propose the following as important habitat:

- *Migratory corridors:* Sweltzer Creek, including where it drains Cultus Lake and joins the Chilliwack River;
- *Spawning and incubation areas*: the lake bed at depths from 1 to 20 m at Lindell Beach, Snag Point, Spring Bay, Mallard Bay, Salmon Bay and Honeymoon Bay, as well as the aquifers that feed these spawning areas; and
- *Juvenile rearing areas*: the lake pelagic zone.

Although the team did not identify freshwater habitat loss as the main cause of the decline, there are nevertheless many impacts on habitat. Since the 1970s, the clearest trend in freshwater habitat is the spread of Eurasian watermilfoil. Other trends include water quality impacts from summer boating and increasing water withdrawal from the Columbia Valley aquifer.

The relationship of Cultus sockeye to its freshwater environment is complex and needs much more study. We do know that salmon carcasses can be an important food source and a substantial contributor of nutrients to freshwater and terrestrial ecosystems and, because Cultus sockeye are lake spawners, nutrients from carcasses are probably directly available to the plankton that drive primary production in the lake. Seventeen fish species other than sockeye occur in Cultus Lake and probably feed directly on carcasses or eggs.

The team believes that conservation of the Cultus sockeye population is biologically and technically feasible, and is not incompatible with fishery exploitation. We recommend a single species conservation strategy for Cultus sockeye that includes research to fill knowledge gaps such as the reasons for early migration, timing relative to the late run, habitat requirements and impacts, relationships with predators and parasites, population dynamics, genetic trends and marine distribution. Fortunately, the scale of conservation can be broadened through cooperation with First Nations (especially the Soowahlie Band and the Sto:lo First Nation), the Provincial and Cultus Lake parks bordering the lake, and stewardship groups. Conservation actions specifically related to harvest will be implemented through Fisheries and Oceans Canada (DFO) and the Fraser River Panel of the Pacific Salmon Commission (PSC).

Conservation Goal

Our Conservation Goal is to *halt the decline of the Cultus sockeye population and return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.* We identify four sequential objectives:

Objective 1

Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful adult spawners with no fewer than 500 successful adult spawners on any one cycle. This objective secures genetic variability.

Objective 2

Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years. This objective ensures the population is growing.

Objective 3

Rebuild the population to the level of abundance at which it can be delisted (designated Not at Risk) by COSEWIC.

Objective 4

Rebuild the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use. This long term objective proposes candidate benchmarks for Cultus sockeye that correspond to our current understanding of the dynamics of Cultus sockeye.

Specific conservation approaches may include control of harvest, short-term enhancement, control of predators and milfoil, and filling knowledge gaps. Maximizing freshwater survival is important, as are maintaining long-term population assessments and raising community awareness.

While further specific actions will be identified in a Program Plan for Cultus sockeye, many are already under way. They include control of exploitation through conservation-oriented fishing plans, population assessment, a captive breeding project, research on the cause of early migration and high pre-spawn mortality, assessment of littoral habitat and the Columbia Valley aquifer, an investigation of adult migratory timing using acoustic tag studies on the impact of predation and control projects for pikeminnow and Eurasian watermilfoil, and awareness materials including a brochure for the general public.

COSEWIC Species Information[1,2]

Common Name: Cultus sockeye
Scientific Name: *Oncorhynchus nerka*
Assessment Summary date: May, 2003
Status: Endangered

Reason for designation: The Cultus population has unique genetic and biological characteristics (migratory delay of adults at the Fraser estuary, protracted lake residency before spawning, exclusive lake spawning, late spawning date, deepwater life of fry). The lack of success with previous attempts to transplant sockeye to Cultus Lake and other lakes suggests that Cultus sockeye are irreplaceable. The Cultus population has collapsed primarily due to overexploitation, including directed and incidental catches in mixed-stock fisheries at levels above those that can be sustained.
An additional key source of impact on spawning adults since 1995 has been very high pre-spawn mortality, associated with unusually early migration into freshwater and with Parvicapsula parasite infestation. There are also ecological impacts to the lake habitat from colonization by Eurasian watermilfoil, land development, stream channelization, nutrient input, and recreational use. Under present conditions, there is a high probability of extinction of the Cultus sockeye.

Occurrence: British Columbia, Pacific Ocean
Status history: Designated *Endangered* in an emergency listing in October, 2002. Status re-examined and confirmed May, 2003.

---

[1] A more detailed review of the causes of the decline in the Cultus sockeye population, including information subsequent to the COSEWIC assessment summary (May, 2003) may be found later in this Conservation Strategy (see *Threats to population viability and habitat*).

[2] The Minister of Environment's decision not to add Cultus sockeye to Schedule 1 of the Species At Risk Act was published in the Canada Gazette on January 26, 2005. Listing the population as *Endangered* was deemed likely to result in unacceptable social and economic costs.

BACKGROUND

"The most recent estimates of abundance are among the lowest recorded for the population."

Distribution

Like most Pacific salmon species, Cultus sockeye is anadromous – it reaches maturity in the ocean but returns to its freshwater birthplace to reproduce. The population thus has life stages that can be found in both fresh and marine waters over a geographic distribution of thousands of kilometres. In some cases, the same waters will simultaneously be home to more than one life stage.

Freshwater distribution

The freshwater part of the Cultus sockeye life cycle takes place exclusively in Canadian waters. The adults spawn in Cultus Lake, 10 km south of the town of Chilliwack in the Fraser Valley. Cultus Lake is one of the more productive sockeye nursery lakes in B.C. and lies in the traditional territory of the Soowahlie Band of the Sto:lo First Nation. It is small, with a surface area of only 6.3 km^2. Adult sockeye enter the lake by way of the Fraser, Sumas, Vedder and Chilliwack rivers, finally connecting with the lake by way of Sweltzer Creek. Following hatching and a period of feeding and growth in the lake, smolts return to the sea by the same route (Figure 1).

The distribution and behaviour of adult sockeye within the lake are poorly known. Spawning itself happens primarily on the lake foreshore at depths between 0.5 and 6 m, although recent observations show spawning as deep as 17 m in some areas. Fry emerge in May and move quickly deeper, open waters where they can be found at depths that vary with the season and time of day (Mueller and Enzenhofer 1991). They rear offshore for one and occasionally two years before leaving the lake as smolts. Because year classes overlap, there is a continuous population of immature sockeye in Cultus Lake. A small proportion (mostly males, termed residuals) never leaves the lake (Ricker 1938, 1959).

Ocean distribution

The ocean distribution of Cultus juvenile and adult sockeye is thought to be similar to that of other late run Fraser sockeye populations, a fact of life history and geography that affects the population's management, harvest and conservation (see *Population Structure* for an explanation of run timing groups). Smolts that pass through the Fraser River estuary and enter the Strait of Georgia in April and May turn northward into Johnstone Strait, then migrate northwest along the B.C. coast until late fall. They then move offshore into the Gulf of Alaska where they spend the next two years feeding with other sockeye populations in the area south and east of Kodiak Island (Burgner 1991). Maturing adults return via Juan de Fuca and Johnstone straits, meaning that a portion of the run swims through U.S. waters before entering the Fraser River.
A life history that sees the species returning to spawn along the same migratory route means that the corridor between the mouth of the Fraser River and the feeding grounds in the Gulf of Alaska can contain juveniles year-round, and both juveniles and adults for much of the summer.

Distribution trends

Ocean distribution does not appear to have altered significantly since scientific records of the timing of spawning migrations through the marine environment began in the 1920s. For Pacific salmon, ocean distribution is affected by two separate migration events: migration *to the river mouth*, and *entry into freshwater*. For Cultus sockeye, timing of the second of these events has changed (see *Biological Limiting Factors* for a fuller discussion of the effects of migration timing on distribution).

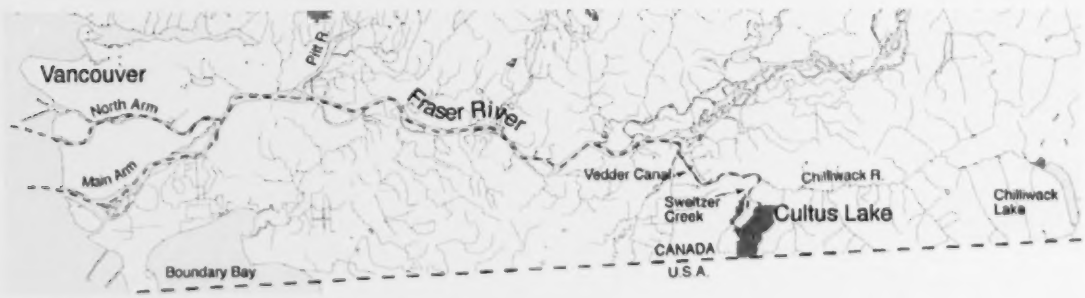


Figure 1. Freshwater migration route for Cultus sockeye. Courtesy: DFO

In the freshwater environment, there has been an apparent reduction in the number of lakeshore areas where spawning occurs, although firm conclusions are difficult to draw because of changing survey methods. By the mid 1960s, Cultus sockeye appeared to have reduced their spawning activity from the six main sites where they had been observed for decades to a single beach (Lindell Beach, a year-round residential area; Figure 2). While this suggests a dramatic reduction in the freshwater distribution of the population, the real situation may be more complex. The recent use of a remotely operated underwater video camera shows that spawning actually continues at a number of the sites but is largely restricted to deeper off-shore waters. This deep water spawning may represent a true change in distribution or may always have happened and is simply more observable with better survey methods (see *Important Habitat* for a fuller discussion of spawning habitat). What is certain is that Lindell Beach itself receives fewer spawning visits than in the past. For example, only a few spawners were observed in 2003 in areas where dense spawning occurred as recently as 1991. There are a number of hypotheses: changes in the quantity and distribution of groundwater at Lindell Beach; encroachment of watermilfoil on the relatively shallow spawning area; more predators between the spawning area and the deep water refuges; and the possibility that shallow spawning areas are sub-optimal and used only when preferred deep water areas are occupied.

Population Structure

Sockeye spawning migrations into the Fraser River are protracted (June to October), and individual populations are assigned to one of four management groups based on similar migratory timing during their return from the ocean to the spawning grounds. Cultus sockeye belong to the *late run* – the latest of these four groups (COSEWIC 2003). The many populations that make up the late run enter the river from early August with an historic peak in late September or early October. They spawn in the lower Fraser, Harrison-Lillooet, Thompson and Seton-Anderson systems. Cultus sockeye have the latest spawning timing of any Fraser River sockeye population (Figure 3).

Pacific salmon populations have multi-year life histories that result in several annual year classes or *cycles*. Fraser sockeye have four such cycles, reflecting a mainly four-year life span. They can have a cyclic pattern of abundance (termed *cyclic dominance*) where one year-class is larger than the other three, or abundance can be similar on all four cycles. Some scientists believe the cycle dynamics reflect biological interactions between populations and their ecosystems (reviewed by Cass and Wood 1994) while others feel cycles are merely a persistent effect of environmental events or harvest policies (Walters and Staley 1987). In the case of the Cultus population, cyclic dominance was not evident until the late 1960s when four distinct cycles were recognized. As Cultus spawners have declined in recent years (see *Trends in population abundance*), cyclic dominance has again become less pronounced.

Genetic differences *between* sockeye populations can be large, reflecting both the post-glacial colonization of their habitats and the characteristics of the lakes where juveniles rear (Wood 1995). Cultus sockeye are highly differentiated from other populations. While the lower Fraser populations appear more similar to one another than to any upper river populations, the Cultus population stands out genetically even from its geographic neighbours (Withler *et al.* 2000).

The population's genetic isolation is mirrored in its distinctive life history (COSEWIC 2003). While transplants among several Fraser sockeye populations have resulted in detectable genetic similarities between the donor and host populations (Withler *et al.* 2000), there is no evidence for this ever happening with Cultus following transplants of sockeye that were made into the lake between 1911 and 1924 (R. Withler 2004, pers. comm.). Although the total number of introduced fry was relatively small (the progeny of about six million eggs) and there were no attempts to match behavioural traits in the transplanted population to those of Cultus sockeye, the apparent lack of genetic mixing suggests Cultus sockeye is irreplaceable.

Figure 2. DFO technicians sampling Cultus sockeye near Lindell Beach, 1995. Photo: Brian Harvey

There is also evidence for genetic differentiation *within* the Cultus sockeye population, as there is for most Fraser sockeye (Beacham *et al.* 2004). Based on limited DNA sampling, there are statistically significant differences in gene frequencies among cycles and among samples within cycles (S. Latham 2004, pers. comm.). In other words, there is low gene flow between cycles. Although the amount of variation between cycles is much less than that between the Cultus and other populations as a whole, it may still complicate conservation: population declines may further reduce genetic exchange among cycles, thereby increasing inbreeding and with it the likelihood of a cycle's extinction.

Trends in population structure

Populations lose genetic variation faster when fewer adults contribute to the next generation. The loss of genetic diversity can best be monitored by analyzing samples over time. Samples of Cultus sockeye DNA have been analyzed for 1992, 1995, 1999, 2000 and 2001.

Changes in the genetic diversity and population structure of Cultus sockeye may already be occurring. In the five years that returning adults were sampled there is a general negative trend in genetic diversity, and cycle-over-cycle changes in population structure are evident (S. Latham 2004, pers. comm.). For example, the 1992 sample is the most distinctive of the five and shows no relative affinity to the 2000 sample from the same cycle. Bearing in mind the beginning of abnormal migration behaviour in 1995 (see *Trends in population abundance*), this means that a distinct and important component of the population structure may already have been lost. We note that sample sizes for some years are small, and the declining trend may result from factors other than reduced population size. Continued sampling is needed.

Some changes in genetic structure may be offset by captive breeding (see *Actions Already Completed or Under Way*). For example, increased genetic drift among cycles will likely be offset by the accelerated maturation schedule of the captive breeding project (D. MacKinlay 2004, pers. comm.). If that project succeeds, it should also limit the loss of genetic richness, and it may also make other analyses possible. For example, changes in genetic fitness can be evaluated by comparing the relatedness of the parent brood stock (the amount of inbreeding) to the fitness of their offspring, the returning adults. This would help us understand of the effects of population reduction (and the resulting inbreeding) on genetic traits that affect survival.

Population Abundance

Cultus sockeye have been studied for many decades. The lake is close to university and government research centres, and the existence of a population of sockeye salmon with noteworthy adaptations to local conditions has resulted in the longest historic series of physical and biological observations of any sockeye population in B.C. A hatchery on Sweltzer Creek (now the site of DFO's Cultus Lake Laboratory) operated from 1916-1936 and was the site of the first-ever comprehensive evaluation of hatchery operations (COSEWIC 2003). The counting fence on Sweltzer Creek has continued to operate since then, providing data on adult escapement and smolt migration extending back to the mid-1920s. Cultus smolts were the first ever to be enumerated in B.C. There is an extensive time series of smolt data through to 1978, although very few data exist from 1979 through the late 1990s.

The development of a conservation strategy for Cultus sockeye is a response to critical population declines. Coincidentally, the continued assessment of Cultus sockeye escapement since 1925, coupled with this small population having historically been intercepted in fisheries on larger, managed populations, means that it represents one of the few cases where the effects of conservation actions can be monitored against solid historic baseline data.

Trends in population abundance

The abundance of *spawners* and *smolts* is measured at the counting fence, while *fry* abundance in the lake is measured by acoustic surveys and sampling by trawl net. There are significant and disturbing downward trends in the abundance of all three life stages.

Spawners

There are two main trends in abundance of *spawners*: (1) between the 1920s and the late 1960s, and (2) from the late 1960s to the present (Figure 3). During the first of these periods, spawner abundance was initially variable, possibly a cyclic pattern but also perhaps reflecting the operation of the Sweltzer hatchery and the periodic control of predators feeding on fry in the lake. By the 1940s, abundance was generally strong in most years and showed a pattern of variability that was more random than cyclic.

The second period (since the late 1960s) is one of pronounced cyclic dominance and steady overall decline (see *Population Structure* for a discussion of sockeye population cycles). Declines are most pronounced on the two less-abundant cycles and probably reflect increased fishing on Weaver sockeye that became much more numerous after a spawning channel was constructed on that river. The strong cyclic pattern of Cultus sockeye since the late 1960s, therefore, is closely associated with a change in harvest policy for late run Fraser sockeye and is unlikely to be a biological attribute of the population.

Although the trends in abundance of each cycle vary, the most recent estimates (2002–2006) are the lowest recorded for each cycle, and yield the lowest generational average. And while a marked decrease in spawners is a warning sign for any salmon population, the situation in Cultus is further complicated by the fact that, in recent years, an unusually high proportion of late run adults has either died in the river on the way to the spawning grounds (en route mortality) or on the spawning grounds before spawning (pre-spawning mortality or PSM). Of the two kinds of freshwater adult mortality, PSM is likely the most important for Cultus; serious en route mortality has not been observed.

This unprecedented loss will be discussed in more detail in later sections. Here it is important only to say that, because not all of those escaping fish will survive to spawn, the loss of the population's reproductive potential is much greater than simply the decline in the number of fish that escape the fishery. The drop in the number of fish counted at the fence over the last three generations, for example, is 36%. But when the high PSM is considered, the rate of decline in successful spawners jumps to a much more alarming 92% (Schubert *et al.* 2002). Factoring PSM into conservation planning is especially difficult because mortality is far from constant, and because the method of estimation has varied between 1995 and the present (PSM was estimated either directly from the number of spent carcasses recovered in the lake or indirectly from the number of smolts produced by each spawner).

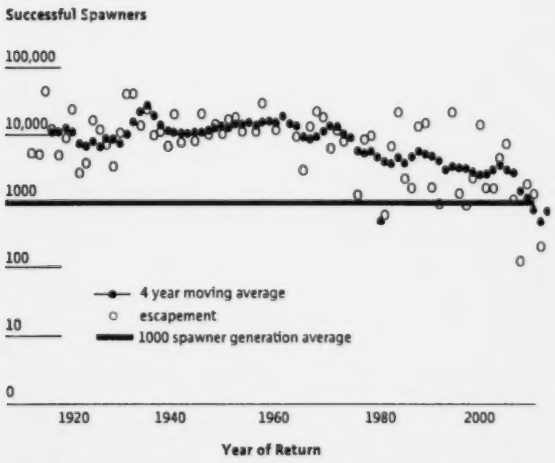


Figure 3. Trend in number of successful spawners in the Cultus Sockeye salmon population.

Open circles are annual estimates of spawning escapement; filled circles are the corresponding estimates smoothed over one-generation (4 yr); line is fitted to smoothed data by LOWESS.

Courtesy DFO.

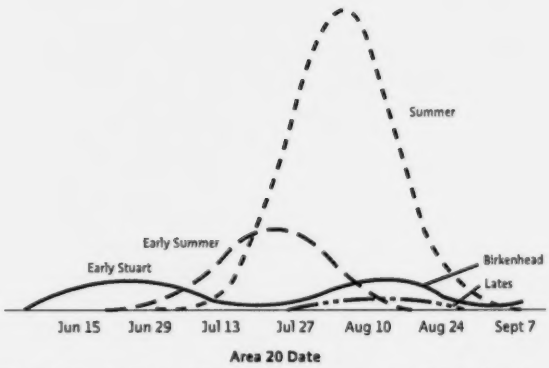


Figure 4. Migration timing of the major Fraser sockeye groups. Cultus belong to the "late" run. Courtesy: DFO

Fry

There is also a downward trend in the abundance of *fry*, although the data are far less complete than for spawners and begin only in 1986. The populations declined from 0.5 - 2.4 million in 1986-1990 to around 250,000 in 1999 and 46,000 in 2000, the lowest for any monitored Fraser sockeye population (COSEWIC 2003).

Smolts

Assessment of the abundance of smolts is fairly complete from 1926 to the mid-1970s, although there are only three assessments from then until 1998. Trends parallel those already noted for adults: strong and variable until the 1960s, then declining. This decline has been dramatic, from a high of more than 3 million in 1937 to a low of 5,700 in 2002 (COSEWIC 2003).

Reasons for the downward trend in spawner abundance are discussed in later sections. There is no detectable decline in the productivity of the lake itself, so the reduced numbers of fry and smolts probably result from a combination of fewer adults returning to the lake, fewer successful spawners and predation on fry. It is difficult to discriminate between the latter two factors because we have no direct estimates of PSM and subsequent smolt production for most years. For example, there were too few carcasses to estimate PSM in the two years (1999 and 2000) when early migration affected late run populations the most. It is not until 2002, a year for which we have direct estimates of both PSM and subsequent smolt production, that we have evidence for predators also playing a role (see *Biological Limiting Factors* for a discussion of depensatory mortality caused by predators). Poor smolt production, if it persists, will affect the rate of recovery.

Biological Limiting Factors

We have already discussed characteristics of Cultus sockeye that make it unique among Fraser River sockeye populations. For effective conservation, it's important to look at the life and habits of this particular population and to identify any special things that put it in harm's way. The following section considers characteristics that need to be dealt with in the planning of conservation actions. Most of them are behaviour traits that are bound up with the concept of genetic uniqueness.

Co-migration

Cultus sockeye are part of a convoy of maturing adults from several Fraser populations, all of which can be intercepted by mixed-stock fisheries along the coast of B.C. and in the Fraser River. Specifically, Cultus fish are part of the late run that includes the more productive and numerically much larger Weaver and Shuswap populations (Figure 4). Any fishery on these larger groups along the migration corridor in August, September and October could also kill Cultus sockeye.

Migration timing

Cultus sockeye are believed to migrate from the North Pacific Ocean into the Strait of Georgia from late July through September, peaking in mid-August (see *Knowledge Gaps).*

Until about 1995, they delayed for up to eight weeks near the Fraser River mouth before resuming their migration into the river, an adaptive behavior thought to lessen exposure to unfavourable conditions in freshwater. Since 1995 and for unknown reasons, the late run began to migrate upstream earlier. The unfortunate result of this early migration has been high *en route* and pre-spawn mortality. Early migration is a biological limiting factor because the behaviour can lead to infection with the freshwater parasite *Parvicapsula minibicornis* (see *Threats to population viability and habitat*). Its possible causes of are being intensely investigated (Cooke *et al.* 2004).

Migration route

Both emigrating smolts and returning adults run a gauntlet of industrial and residential development in the Fraser Valley that has altered the water chemistry and shore habitat in the lower Fraser River and its estuary. Their unalterable route also commits adults to passing through Sweltzer Creek in late summer at a time of heavy recreational use. A 1996 radiotelemetry study revealed that, because Cultus sockeye are relatively inefficient swimmers, they use up unusually high amounts of their limited energy on their freshwater migration (S. Hinch 2004, pers. comm.). Factors that increase their energy needs, such as in-river recreation, can reduce their subsequent spawning success (Hinch and Bratty 2000). Delays or disruptions caused by humans could increase energy use, exposure to high temperatures, stress and susceptibility to *Parvicapsula.*

Freshwater productivity

The ability of salmon populations to recover or sustain exploitation depends on a combination of freshwater and marine productivity that results in their producing more adult progeny than spawned in the previous generation. Historically, freshwater production of about 60 smolts per spawner coupled with a marine survival around of 7% yielded more than four returning adults per spawning parent – a number adequate to sustain the population. However, the recent decline in the number of smolts produced in the lake (COSEWIC 2003) prompted a review of the abundance data to determine whether changes in freshwater productivity could limit the recovery of the population. The review shows that, when there are more than 7,000 spawners, smolt production is variable at an average 68 smolts per spawner. When there are fewer than 7,000 spawners, however, smolt production drops to about half that level. Although the data are variable, there is a consistent pattern of survival throughout the period of record rather than any evidence of a recent decline in productivity associated, for example, with habitat or ecosystem changes. If the recent low freshwater production is due to predation, as is often suggested, the population may have trouble recovering or sustaining exploitation when abundance is below 7,000 spawners. Indeed, the historic data show that recovery has been a problem when the population has declined below 5,000 (see Annex 1). Continued monitoring is required to determine if low productivity will continue, or if higher rates of smolt production can occur at low spawner abundances.

Spawning behaviour

Cultus is one of the few B.C. sockeye populations that spawn exclusively on the lake shore. The population is also particular about the locations it uses for spawning, requiring areas of weathered gravel with a combination of well-circulated lake water and groundwater to maintain the right temperature and oxygen content. The population's preference for lake shores may also mean that infestation with Eurasian watermilfoil reduces access to spawning habitat.

Fry behaviour

Cultus sockeye have a unique adaptation to spawning time: eggs that are spawned later actually develop faster (Brannon 1987). The fry are also unlike most other sockeye fry in that they school and move into deeper waters immediately after swimming up from the gravel – likely an adaptation to the many predators in Cultus Lake (Ricker 1941). The behaviour needs to be taken into account in the design of any predator control programs.

Threats to Population Viability

For many salmon populations, the loss of freshwater spawning and rearing habitat is one of the most important reasons for population decline, and the restoration of habitat has become a touchstone for biologists and community groups. Although there is evidence that watermilfoil, stream channelization and foreshore developments may interfere with prime Cultus spawning sites, freshwater habitat degradation is *not* thought to be the main cause of the population's recent decline. Data collected since the 1930s, although limited by the characteristics that were sampled in earlier years, suggest that the lake itself has changed little over six decades. It remains highly productive, even underutilized, although the watermilfoil population has increased dramatically (Schubert *et al.* 2002) and the effects of developments around the lake have not yet been assessed.

While the following section identifies some specific habitat concerns, the drastic decline in Cultus sockeye is attributed to three other primary causes (COSEWIC 2003):

- Overexploitation in fisheries before 1995, resulting in the population's increased susceptibility to other sources of natural mortality;
- Poor marine survival in the early to mid 1990s which further reduced population levels; and
- Since 1995, high PSM caused by unusually early migrations into freshwater and an associated *Parvicapsula* parasite infection. The high PSM has confounded conservation actions initiated in 1998, which have focused on large reductions in fishery exploitation rates.

The threats are described on the following page in two categories (*natural* and *human-induced*), separated by life stage. Numbers (*e.g., Threat 5c*) are those used in Table 1.

Natural threats

Early migration

Water temperature (Threat 5c). Metabolic processes in cold-blooded animals like sockeye are sensitive to environmental temperature. The early migration of Cultus and other late run populations since the late 1990s has lengthened residence time in freshwater at temperatures that make the already-stressed fish exceptionally vulnerable to diseases and parasites they might normally withstand. For Cultus sockeye, this effect is worsened by the need to migrate through extreme changes in temperature when the fish move from Chilliwack River (moderate temperature) through Sweltzer Creek (high temperature) to Cultus Lake (low temperature).

Hence early migration, while not a threat in itself, has important consequences for Cultus sockeye.

Pre-spawn mortality (Threat 5b). While the cause(s) of the early upstream migration remain to be identified, the effect of the behaviour is well documented. High PSM related to *Parvicapsula* infection has resulted in an unprecedented loss of potential spawners that has pushed the Cultus population to critically low levels and complicates conservation by adding an uncontrollable cause of mortality. The parasite affects kidney function in adult sockeye once they have entered freshwater and may also depress the ability of migrating sockeye to recover from vigorous swimming. Historical PSMs of less than 10% increased in 1999 and 2000 to over 90%. If these levels continue, each spawner would need to achieve more than six times the current level of production for the population to avoid extinction (COSEWIC 2003). There is hope, however, that these very high mortalities are transient: PSM has moderated since 2000 (when it was around 87%), with a 67% loss in 2001, a 13% loss in 2002 and a 23% loss in 2003. There is evidence for increased PSM in 2006, although its magnitude is uncertain.

Egg viability (Threat 1c). Recent studies show no evidence of vertical transmission of *Parvicapsula, i.e.,* infected parents do not pass the parasite on to their eggs and can and do produce viable offspring (A. Farrell 2004, pers. comm.). At present we do not know of any effects of parental infection on offspring fitness (D. Patterson 2004, pers. comm.).

Environmental change

Environmental variability (Threat 7a). Cultus sockeye is as susceptible as any other salmon population to natural climate cycles that occur over long time periods. The survival of all lake, stream and ocean dwelling salmon is linked to these cycles, and changes can affect survival at any life stage. Freshwater conditions can change independently of ocean events, affecting lake productivity and the proliferation of watermilfoil and predators. Given the already depressed condition of the population, a series of such events in freshwater or in the ocean would be a serious threat.

El Niño (Threat 4b). El Niño Southern Oscillation events are one of several periodic phenomena that can reduce the marine survival of Cultus sockeye. *El Niños* increase coastal temperatures and depress productivity (Beamish *et al.* 1997), and may effect migration timing.

Predation

Suckers, sculpins (Threat 1b). Newly hatched alevins may be prey for suckers (*Castostomus macrocheilus*) and sculpins (*Cottus asper*), which frequent the gravel nests or *redds* where the eggs incubate.

Table 1. Summary of Threats to the Cultus Sockeye Population, by Life Stage

LIFE STAGE	THREAT	NATURAL OR HUMAN INDUCED	THREAT CLASS	POSSIBLE SEVERITY (RISK)	IDENTIFIED BY COSEWIC STATUS REPORT?
1. Egg and alevin	a. Habitat alteration	Human	Potential	Unknown	Yes
	b. Predation (suckers, sculpins)	Natural	Known	Unknown	No
	c. Early migration (egg viability)	Natural	Potential	Unknown	No
	d. Pollution	Human	Potential	Unknown	Yes
2. Fry	a. Predation (pikeminnow, salmonids, sculpins)	Natural	Known	High	Yes
	b. Exotic species (Eurasian watermilfoil; incremental pikeminnow recruitment)	Human	Known	Medium	Yes
	c. Diseases and parasites (Salmincola)	Natural	Known	Unknown	Yes
	d. Habitat alteration	Human	Potential	Unknown	Yes
	e. Pollution	Human	Potential	Unknown	Yes
3. Smolt	a. Habitat alteration	Human	Potential	Low	No
	b. Pollution	Human	Potential	Low	No
	c. Predation	Natural	Known	Low	No
	d. Diseases and parasites (Parvicapsula)	Natural	Known	Unknown	No
	e. Diseases and parasites (Salmincola)	Natural	Known	Unknown	No
4. Marine juvenile and adult	a. Global warming	Human	Potential	High	No
	b. Environmental change	Natural	Known	High	Yes
	c. Diseases and parasites (aquaculture)	Human	Potential	Low	Yes
	d. Pollution	Human	Potential	Low	Yes
5. Pre-spawning adult	a. Over exploitation in fisheries	Human	Known	High	Yes
	b. Early migration (prespawn mortality)	Natural	Known	High	Yes
	c. High water temperatures	Natural	Known	Medium	Yes
	d. Recreational activities	Human	Known	Medium	Yes
	e. Habitat alteration	Human	Potential	Low	Yes
	f. Illegal harvest	Human	Known	Unknown	No
	g. Predation (seals, sea lions, river otters)	Natural	Potential	Unknown	No
6. Spawner	a. Exotic species (spawning habitat encroachment)	Human	Known	High	Yes
	b. Habitat alteration	Human	Potential	Unknown	Yes
7. All	a. Environmental variability	Natural	Potential	High	Yes

Pikeminnow, salmonids, sculpins (Threat 2a). Sockeye fry are prey for other salmonids, sculpins (*Cottus spp.*) and the northern pikeminnow (*Ptychocheilus oregonensis*), a large cyprinid common in B.C (Figure 5). At Lindell Beach, schools of fry have been observed being attacked by sculpins before moving to deeper water (Brannon 1965). Pikeminnows are abundant and, while salmonids consume more sockeye fry per individual than do pikeminnows, the sheer number of pikeminnows makes them the greatest threat to the population (Foerster and Ricker 1941; Ricker 1933; Ricker 1941; Foerster 1968; Friesen and Ward 1999).

The pikeminnow diet varies from season to season and with the abundance of prey. In the fall, winter and early spring, sockeye fry and smolts are its most important food while, in the summer, pikeminnow spawners move close to shore where other species serve as prey. In years when sockeye are less abundant, pikeminnows may switch to other species, so it is unclear whether predation is significant at the recent low sockeye abundances. Previous attempts to control pikeminnows suggest that this is a promising conservation approach for the Cultus population (see Mossop *et al.* 2004, and *Approaches to Meeting Conservation Objectives*).

Seals, sea lions, river otters (Threat 5g). Harbour seals and sea lions penetrate the migratory corridor as far as the Chilliwack River and may remove significant numbers of migrating salmon. While the impact on Cultus sockeye is not known, the low numbers of Cultus fish relative to other co-migrating sockeye populations and salmon species may limit the threat. Cultus sockeye would be most vulnerable in the Sumas, Vedder and Chilliwack rivers in August and September. River otters that frequent Sweltzer Creek and Cultus Lake may pose a risk to returning sockeye adults; this threat can in part be mitigated using proactive procedures at the enumeration fence (see *Human-induced threats*).

Diseases and parasites

Salmincola californiensis (Threats 2c, 3e). Cultus sockeye juveniles often become infected by *Salmincola californiensis*, a freshwater copepod that is a parasite on salmon and trout throughout the North Pacific (Kabata and Cousens, 1977). The impact of *Salmincola* on freshwater fish can be considerable, resulting in severe gill damage, reduced growth and smaller egg masses in spawners (Allison and Latta, 1969; Barnetson 2004, pers. com.; Gall *et al.* 1972; Johnson and Heindel 2001; Sutherland and Wittock 1985). Infection rates among fry collected from mid-lake trawl surveys in 2003 were 6% in September and 25% in November (J. Hume 2004, pers. comm.). In 2003, up to 70% of the daily smolt migration was infected with *Salmincola.* Whether the parasite continues to harm the smolts once they enter sea water is not known. In the wild, seawater may kill the parasite directly, kill its eggs or larval stages, or result in the parasite's shedding its larvae without re-infecting the fish.

Parvicapsula minibicornis (Threat 3d, 5c). The effects on adults encountering *Parvicapsula* in the estuary have been discussed earlier in this section. This parasite does not appear to infect juveniles in Cultus Lake (none of the 21 smolts sampled in 2001 were infected). Rather, examinations of Fraser River (but not Cultus) sockeye smolts in the Strait of Georgia in 2000-2001 show that the parasite is picked up in the estuary, but that severity is low and the impact minimal. Very few infected individuals return to the river as adults; however, we don't know whether the smolts die, recover or carry the infection at a barely detectable level. *Parvicapsula* could add to the cumulative risk of PSM among returning adults in years when Cultus sockeye enter the Fraser River earlier than usual, and in years when they spend longer in freshwater.

Human-induced threats

Over- exploitation

Threat 5a. Fraser sockeye are intensively managed using a complex regulatory system involving both Canada and the U.S., in which capture levels set by various bodies depend on the geographic area being fished. Historically, Cultus sockeye adults have been captured in mixed-stock commercial fisheries along their migratory corridor from Alaska to the mouth of the Fraser River (Figure 6).

The term maximum sustainable yield (MSY) is used by fisheries biologists and managers to describe the largest long-term average catch that can be taken without impairing a population's sustainability through natural growth or replenishment (Gulland 1983). MSY for any population reflects a certain exploitation rate (ER). The effect of different ERs is complicated by the varying strength of each cycle and the populations that are being actively managed for a particular year. Mathematical models suggest that the maximum sustainable recruitment for Cultus sockeye is achieved at an ER of 56% (Schubert *et al.* 2002) (Figure 7).

Figure 5. Northern pikeminnow caught during Cultus Lake Pikeminnow Derby, 2003. Courtesy: Frank Kwak

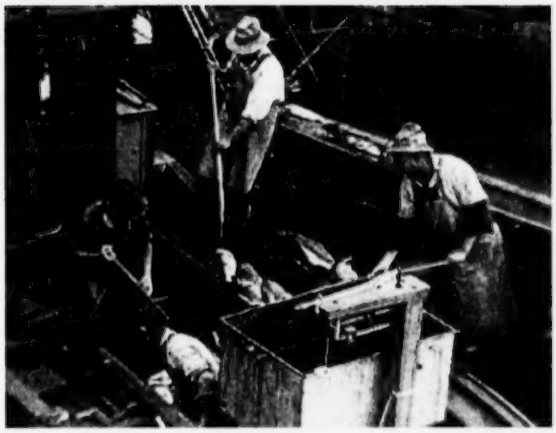


Figure 6. Fraser sockeye at dockside in Steveston, 1946. Courtesy: Pacific Salmon Commission

Until the mid-1990s, ERs for Fraser (and most other) sockeye populations were based on the largest and most productive ones; as a typical smaller population, Cultus was not managed as a discrete unit. Because Cultus has been less productive than its numerically dominant co-migrant populations, it has been subjected to ERs significantly above the level associated with MSY. The long term, cycle-specific ERs for Cultus sockeye have ranged from 67-77% and have frequently been over 80%. Comparison of these rates with the 56% associated with MSY points to fishing as being the single most important reason for population decline in the period before 1995.

Eurasian watermilfoil

Incremental pikeminnow recruitment (Threat 2b). Eurasian watermilfoil (*Myriophyllum spicatum*) is an invasive plant introduced to North America more than a century ago and first observed in Cultus Lake in the late 1970s (COSEWIC 2003). By 1991, it covered nearly half of the lake's total littoral (near-shore) area. The lake is now heavily infested with the plant, which colonizes the bottom to the depth of light penetration. This affects sockeye fry by providing shelter and rearing habitat for juvenile pikeminnow, the adults of which are major sockeye predators. Sporadic control projects in Cultus Lake have shown that mechanical removal of watermilfoil can be effective, although techniques need to be refined and monitored long enough to demonstrate which works best (Mossop and Bradford 2004).

Spawning habitat encroachment (Threat 6a). Dive surveys in 1982 found that dense patches of Eurasian watermilfoil had displaced sockeye from areas previously utilized for spawning. After a removal program in 1983, large numbers of spawners returned to cleared areas (K. Morton 2002, pers. comm.). The effect of watermilfoil, however, is not completely understood. For example, remote video surveys did not indicate that spawning was actually disrupted by watermilfoil colonization (B. Fanos 2004, pers. comm.). However, it is possible that the deep-water areas are sub-optimal for spawning and are being used simply because they are free of milfoil. The impact at current sockeye and watermilfoil population sizes is not known.

Recreation

Threat 5d. Cultus Lake has been heavily used for summer recreation for a century and now receives millions of visitors each year. Apart from habitat alteration and loss (see next section), such heavy recreational use can affect spawners that must make their way through Sweltzer Creek and hold in the lake before finding suitable lakeshore spawning areas. The relatively warm water at the shallow lake outlet and in Sweltzer Creek makes these areas magnets for swimmers in the summer months until Labour Day, and disturbance by swimmers at the lake outlet sometimes delays fish for several hours. Similarly, activity at a campsite beside the creek could disturb fish that are migrating during daylight hours. The sockeye's habit of travelling through the creek mostly at night provides some protection, although nocturnal migration may simply be their way of avoiding disturbance. Angling in the Chilliwack, Vedder and Sumas rivers may also delay migration.

Habitat alteration and loss

Following the arrival of European settlers in the late nineteenth century, human activities at Cultus Lake changed from a First Nations spiritual focus to a recreational one. There are a number of potential impacts to the lake associated with today's two main recreational activities, boating and swimming.

83 000
Spawners that utilize the productive capacity of Cultus Lake
PR model: 2001 and 2002 assessments
Maximum Observed Escaptements
1999 cycle: 82 400 (1927); 70 800 (1909)
2000 cycle: 73 500 (1940)
53 000
Spawners that maximize recruitment
Spawner-Recruit relationship
19 000
Average Escapement, pre-Weaver Production
Cycle averages: 20 200, 33 300, 19 200, 5 000
Equivalent to 20% of Lake Capacity
14 500
Average Escapement, all years
Cycle averages: 14, 200, 27 000, 12 300, 5 000
Equivalent to 17% of Lake Capacity
8 300
Spawners that utilize 10% of the Lake Capacity
Proposed as a limit reference point in Wild Salmon Policy Discussions
1 000
Viable Population (Genetic Criteria)
Cross generation average
500
Minimum Viable Population (Genetic Criteria)
100
Quasi Extinction Threshold
52
Minimum Observed Escapement (2004)

Figure 7. Cultus sockeye population sizes

In the 1950s, sailboats and small inboards were replaced by speedboats, then jet-skis. Boating's main impacts are pollution (hydrocarbons and metals), the construction of piers, and the inadvertent introduction of watermilfoil. Swimming has had a number of impacts, including placement of sand on beaches near the lake outlet, the addition to the lake (until 1976) of copper sulfate to control *swimmers' itch* and the mechanical removal (since 1979) of watermilfoil from swimming beaches.

Threats from habitat alteration are best understood in the context of the history of watershed development in four geographic areas: the *north* or outlet end (Sweltzer Creek); the *east and west sides*; and the *south* end.

The area around the lake outlet and Sweltzer Creek (*north end*) has the longest human history, with evidence of occupation by First Nations for hundreds and perhaps thousands of years (Brown and Flack 2004). Soowahlie Reserve No. 14 was established along Sweltzer Creek in 1864 (D. Kelly 2004 pers. comm.; Figure 8).

The north end of the lake has been popular for recreation since the late 1800s. A road there was constructed some time between 1882 and 1912, and was extended to the south end before the mid-1930s. Development began in earnest in the 1920s, with the construction of boat-houses, a gas station, summer residences and businesses (Figure 9). The lowland areas near the lake outlet were logged in the early 1900s; logging continued at higher elevations, especially on Vedder Mountain, from the 1930s through the 1970s.

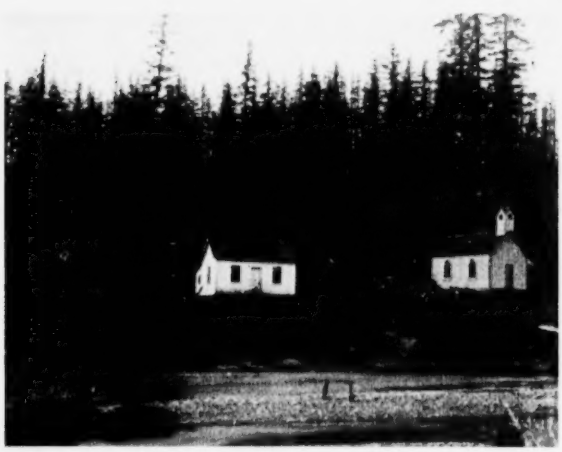


Figure 8. Soowahlie Church on Sweltzer Creek, ca. 1890. Courtesy: Chilliwack Archives

In 1924, the Crown granted land to local municipalities to create a park. Cultus Lake Park was established as a self-governing entity in 1932 on what are now 259 ha at the north end of the lake. Habitat alteration associated with the park includes the removal of shoreline vegetation for beaches, campsites and boat launches, the addition of sand to beaches and the construction of piers. When the park was established, its borders had already been partially logged and included a number of summer residences and commercial developments. Consequently, the Park was granted the power to provide services (water, sewage, roads and electricity) and to establish by-laws to control further development.

Since 1980, developments include golf courses, water slides, boat and jet-ski rentals and riding stables. In 2003, the park had 459 residences, 37 businesses and a year-round population of over 900 in a community that occupies 48% of the park area (Urban Systems 2003).

The Cultus Lake Park Board is currently consulting with governments and the local community regarding a change in governance. The proposed change would permit the Board to borrow money to fund infrastructure projects such as upgrades to water and sewage systems. Such projects could spur further development in areas that have not been designated for park use (*e.g.*, the east side of Sweltzer Creek). Water for the community is supplied by a single well that, until recently, was supplemented by surface water from Hatchery Creek. A recommendation for a second well is under consideration (Urban Systems 2003). The community is serviced by a primary sewage treatment system that includes a collection system and three disposal fields; the system was installed in 1979 and has now exceeded its operational life span. The Sunnyside Campground and residences on Mountainview Road and Park Drive are serviced by individual septic systems. There have been problems with some septic systems and there is a potential for seepage into the lake. Although water quality effects have not been detected, a survey of local and traditional knowledge noted that the water is less clear, the rocks are black, and there is often a bad odour in these areas (Brown and Flack 2004). There are also several storm water runoff systems that discharge directly into the lake.

Early development along the *east and west sides* of the lake was limited by the steep slopes that largely confine the lake shore. In 1948, the 656 ha Cultus Lake Provincial Park was established on both sides of the lake, and the 2,080 ha International Ridge Recreational Area, established in 1969, extends the protected area from the park's eastern boundary to the watershed boundary. The west side remains largely undeveloped.

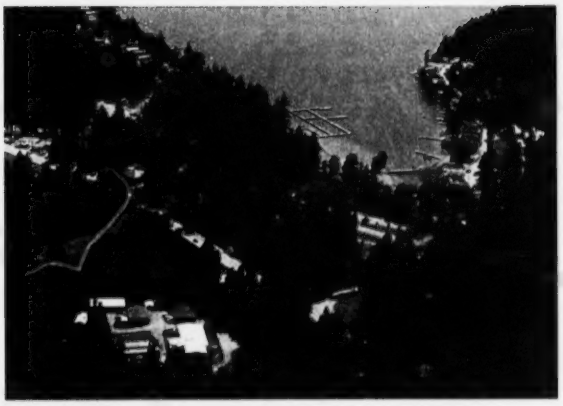


Figure 9. The north end of Cultus Lake, with Sweltzer Creek draining to the left. The cluster of buildings near the bottom left is the DFO Cultus Lake Labratory. Courtesy: DFO

On the east side, the road to the south end of the lake was upgraded in 1950, and visitor services (campsites, boat launches, administrative centre) were developed on four alluvial fans (Entrance Bay, Delta Grove, Honeymoon Bay, Maple Bay). Habitat alterations at these areas include the removal of shoreline vegetation for beaches, campsites and boat launches, the construction of wharves, creek channelization, storm water runoff and the potential for septic system discharge.

At the *south end* of the lake, the Columbia Valley was first settled in the 1890s and subsequently developed as a sparsely populated agricultural area. There is no evidence of prior settlement by First Nations. The valley was logged in the 1920s and the timber shipped south by rail into the U.S. Logging on the U.S. side of the Frosst Creek drainage continued at least until 1986. A debris torrent that year swept log jams into the lake and deposited large amounts of rubble and fine sediments at the delta; extensive dyke improvements followed. The residential community of Lindell Beach, located at the head of Cultus Lake, began to develop in the late 1940s when the original homestead was subdivided into small lots. At about this time, Frosst Creek was diverted from the middle of the beach to the west side of the valley. Today, the Columbia Valley and Lindell Beach comprise a community of 357 residences with a year-round population of about 600 that is serviced by a number of businesses and a golf course. Most of Lindell Beach's lakeshore residents have constructed piers into the lake (Figure 10).

The newer residences are serviced by new septic systems; older ones have septic systems that extend to the lake's edge and probably leach into the lake. The community draws water from the Columbia Valley Aquifer, which drains north into Cultus Lake and south into the U.S. The water is largely uncontaminated, although nitrate-nitrogen concentrations (from manure and fertilizer) are higher than normal (Zubel 2000). Current water use consumes less than 1% of the annual recharge. The Lindell Beach water system was upgraded in 1995, with a new well and distribution system. Until recently, Lindell Beach was a heavily utilized sockeye spawning area (see *Distribution trends*). The movement of spawners away from Lindell Beach may reflect changes in the groundwater hydrology resulting from activities such as concentrated residential development, creek diversions and dyking, the construction of piers on the spawning grounds, and the draw-down of the aquifer where it enters the lake. There are anecdotal reports that the amount and distribution of groundwater along the beach has changed since the late 1980s (Lindell Beach residents; K. Peters 2004, pers. comm.).

Potential threats from habitat alterations are described by life stage below.

Eggs and alevins (Threat 1a). Habitat alterations that pose a threat to eggs and fry include those that affect water and spawning gravel quality. A preliminary test of subsurface water quality shows contaminant levels that may threaten the population (K. Shortreed 2004, pers. comm.). Surface water quality may be affected by sedimentation from logging and other developments in the Frosst Creek watershed, leachate from septic tanks, and storm drain runoff.

Fry (Threat 2d). There is no obvious change in the physical and biological characteristics of the lake. Removal of riparian (shore-dwelling) plants could affect the lake's temperature profile, and adding sand to popular swimming beaches near the lake outlet could affect ecosystem linkages.

Smolts (Threat 3a). Habitat alterations that pose a threat to smolts occur along the freshwater migratory route. An active gravel mine on Parmenter Road produces sedimentation that enters Sweltzer Creek and could harm migrating sockeye (Figure 12). A proposed mine expansion may reduce habitat and water quality, increasing turbidity and pollution from fuels and lubricants.

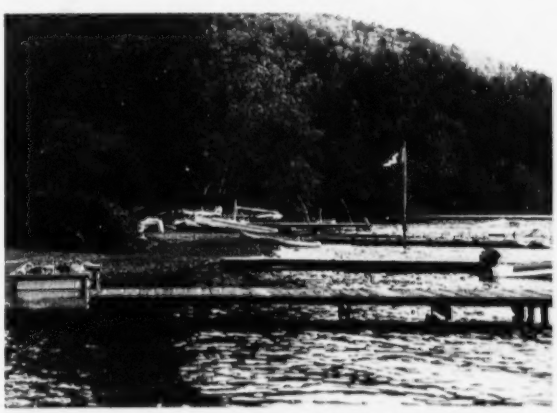


Figure 10. Private docks extend from Lindell Beach. Photo: Brian Harvey

The applicant is expected to undertake further work to satisfy DFO and the Ministry of Energy and Mines with respect to erosion and sediment control.

Pre-spawning adults (Threat 5e). Potential threats to adults along the freshwater corridor include gravel mining, especially in the Vedder River, as well as alterations to Sweltzer Creek that reduce habitat quality or force the fish to delay in sub-optimal habitats. These may include the blockage of cool water seepage channels from the Chilliwack River and the structure at the lake outlet that controls lake water levels.

Spawners (Threat 6b). Habitat alterations that pose a potential threat to adults resemble those identified under *Threat 1a* (wharf and pier construction, alteration of creek channels, addition of sand to beaches). Increased withdrawal from the Columbia Valley aquifer by the new Lindell Beach well may reduce groundwater percolation into the spawning areas.

Pollution
Eggs, alevins and fry (Threats 1d and 2e). Sockeye rely on high quality, well-oxygenated water for incubation. There are a number of potential pollution sources in Cultus Lake and its watershed that could degrade lake water quality. Inadequately treated sewage from residences and campsites may enter the lake and, although there is no agriculture adjacent to the lake, farms in the Columbia Valley, golf courses and residences around the lake use fertilizers and other chemicals that may enter the lake directly or through groundwater. Goose feces contain nitrogen and phosphorus as well as coliform bacteria, and the number of Canada geese using the lake as a nighttime refuge and feeding area has increased with the increase in open green areas around the lake. Feces from waterfowl could increase the nutrient load in the lake, causing productivity shifts that could affect juvenile sockeye.

Summer boat traffic has increased to a level where the Canadian Coast Guard is considering imposing traffic control regulations. Boat engines, particularly 2-cycle outboard motors, emit hydrocarbons and metals; sub-surface samples of water in spawning gravel show levels of several sediment-bound metals that exceed criteria for open water (Hume 2004 pers. comm).

Smolts and marine juveniles and adults (Threats 3b and 4d)
Effluent from communities and industry can pose a threat to Cultus juveniles and adults in the lower Fraser and in estuarine and coastal waters.

Illegal harvest (Threat 5f)
Illegal harvest or poaching in the Fraser River and associated migratory corridors has long been known about but never completely controlled. As noted with the threat of predation by marine mammals (Threat 5g), the low abundance of Cultus sockeye relative to other co-migrating species and populations limits the impact in most areas. Cultus sockeye are at greatest risk when they outnumber other populations, namely in the Sumas, Vedder and Chilliwack rivers in August and September and at any time in Sweltzer Creek and Cultus Lake.

Diseases and parasites from aquaculture (Threat 4c)
Juvenile sockeye that migrate through areas of intensive coastal net-pen salmon aquaculture may be susceptible to elevated levels of sea lice infection (Gardner and Peterson 2003). This threat is the subject of intensive research (PFRCC 2003).

Enumeration fence (Threats 5c, 5g)
The Sweltzer Creek fence (Figure 13) has the potential to cause migratory delays in Sweltzer Creek, exposing the returning adults to high water temperatures and an increased risk of predation by river otters. Careful adherence to operating procedures is required to eliminate this threat.

Global warming (Threat 4a)
In contrast to natural long term shifts in ocean temperatures, longer term human-induced changes in climate may have profound impacts on the distribution of salmon and other aquatic species. The most common current hypothesis has salmon populations shifting northward.

Habitat Identification

General habitat requirements
Section 2(1) of the Species at Risk Act (SARA; see http://www.sararegistry.gc.ca) defines the habitat of aquatic species as *"spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced."* While the Cultus population was not listed as *Endangered* by the Minister of Environment and, therefore, does not fall under SARA jurisdiction, the Recovery Team chose to identify important habitat in a manner consistent with SARA. The definition clearly applies to species such as Cultus sockeye whose habitat requirements are geographically wide-ranging and cover a variety of ecosystems. In common with most Pacific salmon species, the population divides its life cycle between freshwater (for spawning, egg incubation and hatching, fry rearing and smolt migration) and the ocean (growth from smolt to adult, followed by return migration to the natal freshwater location). As the above definition implies, each of the major life stages has different habitat requirements.

The marine habitat requirements for Cultus sockeye are those generic to all Pacific salmon species and include unrestricted ocean corridors and feeding grounds with the right temperature and productivity (Foerster 1968; Burgner 1991).

Although climate-driven natural variability in ocean productivity will influence the survival of Cultus sockeye, the management of marine habitats other than the migratory corridor is probably impossible, and we do not discuss these habitats further. The following sections relate solely to freshwater habitat and describe what Cultus sockeye need for survival and recovery. Aerial and diagrammatic views of this freshwater habitat are provided in Figures 11 and 14.

Important habitat

Determining the importance of habitat to Cultus sockeye – or to any aquatic species that ranges widely for feeding, growth and reproduction – is not easy. Watersheds differ in their hydrology, temperature regime, sediment transport, nutrient cycling, physical structure and biological processes, so there is no "one size fits all" definition of aquatic habitat for Pacific salmon in general. And because all fish populations develop unique adaptations to the environmental conditions they encounter and to the species with which they share their habitats, the habitat that is important for each population is correspondingly unique.

It is also hard, when considering several examples of the same category of habitat, to decide which ones are most important. For example, when a population of fish uses a dozen spawning beaches, should we single out one and gamble that losing it will be the straw that breaks the population's back, and invoke all the relevant measures for its protection? Or should we include all the beaches because it's impossible to predict which will be used most by a population so diminished that spawning pairs are hard to spot at all? Caution dictates treating them all as important and meriting the protection provided under the *Fisheries Act*.

Figure 11. Aerial view of Cultus Lake. The developed north end is at bottom right. Courtesy: DFO

The following discussion concerns freshwater habitat that the Recovery Team considers important for conservation of Cultus sockeye. Our discussion focuses on three types of habitat: juvenile and adult migratory corridors; spawning and incubation areas; and juvenile rearing areas. We describe in a general way the requirements for each type of habitat, comment on specific characteristics of the habitats used by Cultus sockeye, then propose habitats that we believe are important to the population.

Habitat in migratory corridors

Migrating adult sockeye require holding or resting sites, suitable water flow and acceptable water quality. In large unregulated rivers, sockeye migrate near the bottom or the shore and are generally unimpeded except by fast water or predators. In smaller rivers, the fish swim in bursts through shallow areas and rest in deeper pools. Consequently, flows must be sufficient to allow passage over riffles and barriers, and large woody debris and boulders are needed to provide resting areas and cool water refuges. Riparian vegetation moderates water temperature and can provide protection from predators. Excessive temperatures, turbid or otherwise poor quality water can cause delays and promote disease. Key habitat attributes for adults, therefore, are water depth, quality, temperature and flow, with resting areas and refuges.

Migrating juvenile sockeye require similar habitats as well as specific photoperiod and water temperature regimes to trigger the change to smolts at the appropriate time. A normal range of stream flows and temperatures maintains the temporal pattern of migration, and physical structures such as undercut banks and large woody debris provide rest areas and cover from predators. Key habitat attributes for juveniles, therefore, are water depth, flow and temperature, with cover and channel complexity.

How do Cultus sockeye fit this pattern? They use a freshwater corridor that extends from the Fraser River estuary to Cultus Lake itself. In the *lower Fraser River*, fish migrate through an unobstructed shipping channel that is dyked and regularly dredged. They are vulnerable to any fishery during their migration, especially to poaching and predation by marine mammals if they hold at the mouth of the Sumas River. They are also affected by high water temperatures (up to 20°C) if they migrate into the river earlier than normal; such temperatures increase their vulnerability to disease and parasites and can lead to increased mortality (Schubert *et al.* 2002).

Risk increases as Cultus sockeye leave the Fraser River and move into the Vedder and Chilliwack rivers, the middle legs of the freshwater corridor. The lower *Vedder River* is closely confined by dykes, while the upper river has set-back dykes that allow it to meander over a broad floodplain. Both parts of the river suffer from regular gravel removal, channelization,

bedload movement, sediment deposition and the loss of riparian vegetation. Here, predation and poaching become more of a threat because the buffering effect of large co-migrating populations has largely evaporated and the channels are shallower and more open. Although temperatures in the Vedder and Chilliwack rivers are normally moderate (<18°C), migration can be slowed or halted for hours to days by high flows caused by heavy rain (Hinch 2004, pers. comm.) or by angling and other recreation like kayaking and canoeing. The Vedder River becomes the *Chilliwack River* at Vedder Crossing, just downstream from its confluence with Sweltzer Creek. It provides holding habitat before the sockeye migrate into *Sweltzer Creek*, the final leg of the freshwater corridor.

Sweltzer Creek is short and relatively shallow with little channel complexity or large woody debris (Figure 12). Water temperatures can exceed 25°C in August and September, although cut-off seepage channels from the Chilliwack River and groundwater infiltrating pools may provide cooler refuge areas. Prolonged exposure to such temperatures can be lethal to sockeye. Any delays while swimming up Sweltzer Creek may decrease spawning success or increase mortality.

Some activities of concern are angling near the mouth, swimming at a campsite in the middle reaches, swimming in the upper reaches and around the lake outlet, boating and the operation of a low level weir (to control lake levels) at the lake outlet. The population is very vulnerable here, so the maintenance or improvement of creek habitats is critical to its survival and recovery.

The Recovery Team identified Sweltzer Creek, including where it joins Cultus Lake and the Chilliwack River, as *important habitat* for Cultus sockeye. For the population to have a chance at recovery, obstruction and disturbance need to be minimized so that the fish pass through the three kilometres as quickly as possible. Further study is required to mitigate the effects of habitat alterations and to optimize key habitat attributes such as temperature, resting areas and cover. Activities likely to destroy habitat include changes to channel morphology that reduce water depth or pool frequency, removal of riparian vegetation, water extraction and sedimentation. Activities that may threaten the population are those that would delay fish in the creek, including recreation in and near the creek and at the lake and creek outlets (Figure 13).

Habitat used for spawning and incubation

Sockeye choose spawning and incubation habitat based on substrate composition and permeability, water quality (*e.g.*, oxygen content), temperature and water flow through the substrate. Some populations, such as Cultus, spawn exclusively along lake shores where the presence of upwelling groundwater and circulating lake water are key attributes.

The timing of salmon life cycles reflects the chemical, physical and biological characteristics of their habitats. The timing of fry emergence, which is key to subsequent growth, is a genetic characteristic of the population and is hence the major evolutionary determinant of the timing of spawning (Brannon 1987). Cultus sockeye spawn late in the year, from early November to early January, and thus may require incubation areas where warmer groundwater (8°C) mixes with cooler lake water (average 6.4°C, but as low as 2.5°C) so that eggs can develop fast enough to emerge in April and May (Ricker 1937a, Brannon 1987. K. Shortreed 2004, pers. comm.). Thus, groundwater is important to the development of those eggs that are deposited late in the year, and may have a more general importance when winters are colder. It also removes the fine sediments and metabolic wastes that, in river spawning populations, are removed by the current.

Because it takes 50 years for rain water to seep through the Columbia Valley aquifer and into the lake, groundwater has little or no oxygen (M. Zubel 2004, pers. comm.). The population, therefore, also relies on oxygenated lake water. In Cultus Lake, spawning areas are irrigated by the vertical mixing of highly oxygenated surface water that begins in December when surface water cools and becomes denser and the strong north or north-west winds promote its mixing with deeper water (Ricker 1937a). The process is called *winter circulation*, and continues until March or April. Because wind intensity varies across the lake, the strength of circulating lake currents may also vary from place to place. Consequently, the substrates selected for spawning in areas with less circulation may have to be more permeable to permit oxygenated water to reach the eggs. Thus, the key attributes of spawning and incubation habitat reflect a complex interaction between temperature and oxygen regimes and substrate permeability.

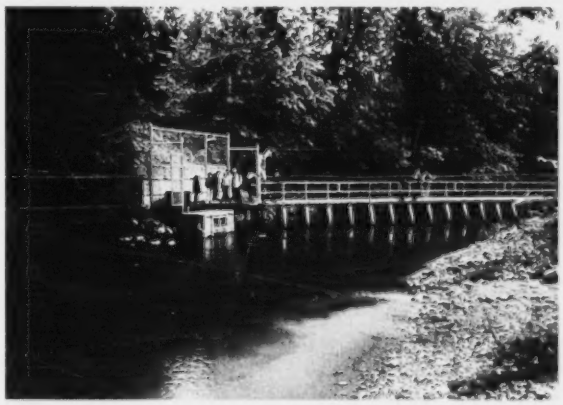


Figure 12. Silt washed into migratory habitat in Sweltzer Creek, 2004. Photo: Brian Harvey

Figure 13. Disturbance of migratory habitat near the counting fence, 2002. Photo: Jenna Hauk, *The Chilliwack Progress*

Current and historic spawning areas in Cultus Lake comprise about six hectares of weathered cobble and gravel along the lake shore at Lindell Beach, Snag Point, Spring Bay, Salmon Bay, Honeymoon Bay and Mallard Bay. Surveys using a remotely operated vehicle (ROV) show that only about half of those sites were used in 2002-4, mostly at Spring Bay, with a few spawners at Lindell Beach, Salmon Bay and Honeymoon Bay (Figure 14). Spawning has been observed at depths of 0.5 to 6 m, and more recently in much deeper water (10 to 17 m).

Because the deeper waters have not been assessed until recently, it is not possible to determine the type of spawning habitat Cultus sockeye prefer. Two possibilities exist. On the one hand, if the shallower areas where spawners were historically observed are the preferred habitat, then recent impacts such as the encroachment of watermilfoil, changes to the aquifers and physical alteration of the beaches may have caused spawners to move to deeper water. If this is the case, the shallower areas require urgent attention. On the other hand, if the deeper habitats are preferred and the shallower habitats are used only when abundance is high (as it was until the late 1960s), then the total spawning area may be underestimated. Either way, while there may be enough habitat available for the current low spawning populations, it may be both quantitatively and qualitatively inadequate for the larger, recovered ones envisaged by the Team.

The Recovery Team identified areas of lake bed at depths from 1 to 20 m as *important habitat* for Cultus sockeye at the following locations: Lindell Beach, Snag Point, Spring Bay, Mallard Bay, Salmon Bay and Honeymoon Bay. Given the dependence of the population on groundwater, the Team also identified the aquifers that feed these spawning areas as *important habitat*. Further study is required to determine the precise location and extent of habitats with the appropriate combination of substrate and water quality (particularly temperature and oxygen). Such habitats will need to have an acceptable level of impact from watermilfoil encroachment and land and water use activities, and be large enough to support the number of spawning pairs envisaged in this strategy. Activities likely to destroy spawning and incubation habitat are those that would increase sedimentation in the lake (*e.g.*, removal of riparian vegetation or forest cover near the lake shore and tributary creeks, mining, road construction), alter the quantity and quality of the groundwater (*e.g.*, water withdrawal, leaching of fertilizers or sewage), alter the quantity and quality of surface water (*e.g.*, septic seepage) or physically disrupt the spawning areas (*e.g.*, foreshore development).

Juvenile rearing habitat

To identify the habitats that are important to juvenile sockeye, especially those in Cultus Lake, it is necessary to have a basic understanding of how lakes function. Cultus is a *warm monomictic* lake, which means that its surface and deeper waters form distinct layers in spring, summer and fall and mix only when the surface waters cool to the temperature of the lower depths. Mixing brings nutrients to the surface and returns oxygen to the lower levels (see *Spawning and incubation habitat*). In spring, the surface water heated by the sun becomes less dense and "floats" on the cooler, denser water below. As heating continues, the surface layer's temperature and density inhibit mixing. The lake is then said to be *stratified*, with a warm upper layer (the *epilimnion*), a transition layer (the *metalimnion*) where temperatures decrease rapidly with depth and a lower layer of cold, dense water that extends to the lake bottom (the *hypolimnion*). Because the lake has a zone where temperature drops rapidly, it is said to have a *thermocline*.

In Cultus, warming begins in April and the thermocline that is established by late May persists until November. The epilimnion typically goes down 6 to 8 m and its temperature can exceed 22° C in August. The metalimnion is normally several metres deep. Hypolimnetic temperatures are cool (5-8° C) throughout the year (Ricker 1937a).

Cultus' small size and its typically calm and warm summer weather result in temperatures in the epilimnion that approach the lethal limit for sockeye. Because it is also an unusually clear lake where enough light to support plant growth can penetrate the cooler waters of the hypolimnion as deep as 16 m, water clarity is an important habitat attribute. Photosynthesis is controlled by the availability of nitrogen and phosphorus as well as light, and is one of the key factors controlling a lake's capacity to rear juvenile sockeye. Cultus has unusually high nitrogen and phosphorus concentrations that, along with its favourable light conditions, result in the highest photosynthetic rate of any sockeye nursery lake in the Fraser system and permit zooplankton (organisms that prey on the phytoplankton and are in turn eaten by sockeye fry) to flourish in a community structure favourable to sockeye fry. Although zooplankton are scarce in the upper 5 m where the water clarity makes

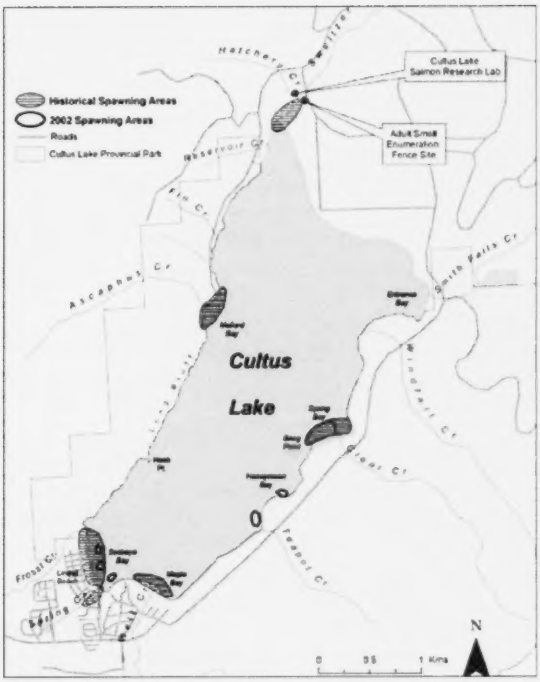


Figure 14. The main spawning beaches used by Cultus sockeye. Courtesy: DFO

them highly visible to hungry sockeye, they are abundant to greater depths than in most lakes. Ricker (1937b), in the only assessment of the vertical distribution of Cultus zooplankton, estimated their summer daylight range at 5 to 15 m, an area that includes the lower part of the epilimnion, the metalimnion and a narrow strip of the hypolimnion. Thus, water clarity is a key habitat attribute that allows sockeye to avoid the unfavourable summer conditions in the epilimnion.

The habitats used by juvenile sockeye are determined by their behavioral responses to key habitat attributes. These attributes are physical (*e.g.*, water temperature, lake stratification, water transparency), chemical (*e.g.*, oxygen) and biological (*e.g.*, plankton, competitors, predators; Foerster 1968). Fry reside in cool, deep waters (probably near the bottom) during the day and migrate upward at dusk when the light diminishes enough to reduce their detection by visually feeding predators. They actively feed in the upper part of the lake, including the epilimnion when temperatures are favourable, when light levels are sufficient for them to detect their prey. During the spring, summer and fall, they form a nighttime layer 5 to 10 m deep just below the epilimnion (Schubert *et al.* 2002). When stratification breaks down in the winter, they are found at all depths at night. When dawn approaches, they again feed in the upper water column before descending to the bottom for the day. Such pronounced vertical migrations are often used by fish to maximize feeding opportunities, avoid predators, and reduce metabolic costs (Bevelhimer and Adams 1993). Cultus sockeye fry face very little competition for food from other species; freshwater survival and growth rates are adequate at all densities observed to date (Ricker 1937b; J. Hume 2004, pers. comm.). Thus, adequate food, while a key habitat attribute, does not appear to limit sockeye fry populations in Cultus Lake.

The predator community is another key habitat attribute of Cultus Lake. Predation is the most important source of mortality in the lake and occurs all year. Prickly sculpins eat sockeye fry before and during emergence; Dolly Varden char, trout and salmon eat them in the spring and summer; pikeminnow join the list of predators in the fall and winter and during the smolt migration in the spring (Mossop *et al.* 2004). Despite such mortalities, the current ability of the lake to produce sockeye smolts is generally good, although sockeye production would be higher if the predator populations were reduced. While the lake appears to retain its ability to support the offspring of up to 80,000 adult sockeye, predation on small populations (such as now exist) may limit the ability of the population to recover – a special worry given the apparent doubling of the pikeminnow population since the 1930s which may in part result from improved habitats provided by Eurasian watermilfoil. Thus, the predator community is a key habitat attribute that may limit recovery.

The Recovery Team identified the lake pelagic zone (*i.e.*, open water areas where light does not penetrate to the bottom) as *important habitat* for Cultus sockeye. The thermal structure of the lake in relation to the fry's food supply results in a precarious balance that allows the young fish to avoid lethal water temperatures while retaining access to food. Activities that could destroy this habitat are those that influence water clarity (like increased turbidity from land and water use and increased phosphorus loading from fertilizer runoff) or sewage effluent that could produce undesirable phytoplankton blooms. Further study is required to understand and mitigate predation impacts at small population sizes.

Habitat trends

Since the 1970s, the clearest trend in freshwater habitat is the spread of Eurasian watermilfoil. The plant propagates rapidly by fragmentation, and there are now so few spawners that the substrate cannot be kept clear by the fish themselves. Newly observed spawning below the limit of watermilfoil growth may be a response to the overgrowth of previously preferred spawning areas. With the number of spawners so low, however, it is unlikely that spawning area is limiting, although there clearly need to be sufficient spawning sites for the increased numbers of adults expected from the actions outlined in this Conservation Strategy.

Other habitat trends include water quality impacts from the expanding summer boating community, and increasing water withdrawal from the Columbia Valley aquifer.

Habitat protection

The fact that most of the riparian zone is already parkland is a mixed blessing for Cultus sockeye. On the plus side, much of the park riparian zone is still natural, certain kinds of development are already prohibited and there already exists a park administration for communicating with visitors. On the negative side, parks – especially those as close to major urban populations as Cultus Lake – attract visitors at just the time of year when a precarious adult sockeye population needs undisturbed access to high quality migration corridors and spawning habitats.

We have identified three habitats that must be protected to ensure the viability and recovery of the population: the key spawning areas and the aquifers that feed them; the migratory corridor of Sweltzer Creek; and the lake's highly productive pelagic zone. In addition to protection, there are several kinds of restoration that could ensure quality habitat remains available for the population: removing watermilfoil (Newroth 1993); creating new spawning areas or rehabilitating existing ones (M. Foy 2004, pers. comm.); and improving the creek channel to facilitate migration.

The protection and restoration of habitats will benefit from raising awareness among people who can affect the lake, its riparian zone and associated streams. Awareness is a prerequisite to motivating stakeholders to reduce habitat impacts. People who might be receptive include farmers, recreational boaters and swimmers, cottage owners and Soowahlie Band members. Possible tools include signs, brochures, media coverage, meetings with community leaders and park managers and increased enforcement of the *Fisheries Act*.

Ecological Role

It is well documented that salmon carcasses can be an important food source and a substantial contributor of nutrients to freshwater and terrestrial ecosystems (Naiman *et al.* 2002). Since over 95% of a salmon's adult weight comes from the ocean, its life cycle is actually a mechanism for the upstream transport of marine nutrients such as phosphorus (9 g/adult) and nitrogen (65 g/adult). The decomposition of carcasses is thus an important source of both food and nutrients and can make up a significant proportion of the annual nutrient load in a lake (Schmidt *et al.* 1998). Because Cultus sockeye are lake spawners, these nutrients are probably directly available to the lake phytoplankton, and less available to the terrestrial ecosystem, than would be the case for a population that spawns primarily in streams. The nutrients can increase the productivity of microscopic plants and animals growing on underwater surfaces (Shortreed *et al.* 1984), with subsequent benefits to invertebrates and ultimately to fish. Many of the bird and animal species of Cultus Lake are known to feed on salmon carcasses or eggs (*e.g.*, eagle, gull, waterfowl, Steller's jay, raccoon, mink and otter); 17 fish species other than sockeye occur in Cultus Lake, and in other lakes or streams a number of these feed on carcasses or eggs. In addition, when sockeye spawners are abundant there are more juveniles available as food for predators. Although the effect of the decline of the sockeye population on other components of the ecosystem will be difficult to quantify, for most species a decline in the food supply usually results in a reduced population size.

The direct contribution of Cultus sockeye spawners to the lake ecosystem has never been studied, although their possible importance has long been acknowledged (Ricker 1937b). Nutrient models (Vollenweider 1976) show that the amount of phosphorus available to phytoplankton in Cultus Lake would increase by about 5% for each 10,000 sockeye spawners. The highest recorded spawner population (82,000) would thus have increased the phosphorus levels by one-third, suggesting that detectable increases in productivity of the lake's limnetic zone would happen only with higher escapements.

Cultus sockeye are presently a candidate indicator species for ecosystem monitoring (Fraser Basin Council 2002), and the Chilliwack watershed will be part of a pilot federal-provincial project to develop a watershed fish sustainability plan (M. Johnson 2004, pers. comm.).

Importance to People

Cultus sockeye are harvested in commercial, recreational and First Nations fisheries along the south coast of B.C. and in the lower Fraser River (Figure 15). These fisheries have substantial economic and cultural importance. While Cultus sockeye are a minor component of these fisheries, their harvest contributes to and makes possible the much larger harvests of the other salmon populations.

The population is particularly important to the Soowahlie Band of the Sto:lo First Nation. Historic colonization of the area by First Nations was strongly influenced by sockeye in the lake and Sweltzer Creek. Cultus sockeye is prominent in Soowahlie cultural expression and its conservation is a high priority with the Band. The population also has great importance for other Sto:lo bands.

The long-running role of Cultus sockeye as a subject for scientific study means that the population has special significance for naturalists and for the scientific community as a whole. There has been considerable basic research using the population as a model to understand the general biology and ecology of sockeye. There are few populations of any animal that have been monitored as long as Cultus sockeye and the data currently being collected, especially at such a perilous time for the population, are invaluable for the understanding of conservation processes in general.

Figure 15. First Nations fishing vessel in the lower Fraser River. Courtesy: Pacific Salmon Commission

Finally, people in British Columbia place high value on healthy habitats with viable salmon populations, and many community groups have worked for years to restore habitat and promote conservation of salmon biodiversity. For these people, the prospects for Cultus sockeye are of great interest.

Knowledge Gaps

Despite intensive study of Cultus sockeye over many decades there are still significant knowledge gaps that affect its potential for recovery. The main ones are listed below, with an indication of how filling them will affect the population.

Early migration

Reasons for the early upstream migration of late run sockeye are not known and there is only limited understanding of how early migration relates to high PSM for the Cultus population. The roles of parasites and disease (*e.g., Parvicapsula*) in causing high mortality need to be investigated, as do the effects of early migration on the fitness of subsequent generations. An understanding of the causes of early migration and the ability to predict the severity of PSM are critical to the development of the fishing plans and the in-season management tools required to conserve the population.

Timing and productivity

Our understanding of the productivity of Cultus sockeye is based on the assumption that they are exploited at the same rate as other late run populations. This implies that they return from the North Pacific Ocean to the Strait of Georgia and into the Fraser River at the same time and pass through the fisheries in the same pattern. There is evidence that this assumption may be incorrect: a fin–clip study in the 1930s shows that Cultus sockeye may actually return from the North Pacific a week or two later and over a longer period than other late run populations, and assessments at Mission and Sweltzer Creek show a later (by one month) and more protracted migration of Cultus sockeye into the river. These assessments may mean that Cultus sockeye have a later and broader marine migration pattern and that they delay for several weeks in the estuary or the lower Fraser River. If this is true, then historic catch estimates are wrong. For example, fisheries that would catch the earlier-migrating late run populations might be closed before most of the Cultus fish arrive.

This is a significant knowledge gap that affects our understanding of the population's susceptibility to fisheries in different areas and at different times and directly affects our understanding of its productivity. What we know about productivity is important for planning fisheries on co-migrating summer and late run populations and is central to our assumptions of how such fisheries affect conservation efforts. For the conservation strategy to be effective, adult migratory timing needs to be investigated using modelling, improved stock discrimination techniques and the use of acoustic tags that are applied to smolts but activate on the return spawning migration.

Habitat requirements and impacts

When it comes to understanding the threats to the population, the weakest links may be our knowledge of habitat capacity and the impacts of habitat change. The overall importance of such impacts is difficult to assess because there are significant knowledge gaps about how habitat is used by various life stages of Cultus sockeye. Measures for protecting habitat will be much better designed and justified if they are based on solid data. Some of the more important knowledge gaps related to habitat are:

- **Amount and distribution of spawning habitat**: Although spawning areas are generally known, their extent is not well documented and other important areas may have gone undetected. Quantifying and mapping habitats based on characteristics such as appropriate substrate and the presence of circulating lake and subsurface water will improve our understanding of spawning capacity and help us protect important habitat;
- **Spawning habitat utilization**: We need information on the amount of spawning habitat required by a single spawning pair. This will allow us to quantify the amount of spawning habitat that is needed by a recovered population;
- **Eurasian watermilfoil distribution**: There is a need to map the watermilfoil distribution in the lake. This will improve our understanding of its potential impact on spawning distributions and fry survival and allow us to develop actions to mitigate the threat;

- **Recreational boating:** Cultus is a small lake with a very large recreational boating community; its habitat may be the most affected of any lake in B.C. The ecosystem role of hydrocarbons and metals from recreational boating needs to be evaluated to determine if they pose a threat to the population;
- **Columbia Valley aquifer**: There is anecdotal evidence that the apparent redistribution of spawners away from Lindell Beach may be associated with a reduction or loss of groundwater percolation on parts of the beach. Because we believe that groundwater plays an important role in the successful incubation of eggs, we need an improved understanding of the Columbia Valley and other local aquifers. Specifically, we need to know the impact of precipitation patterns, water extraction and habitat development, and we need to learn about how the aquifer supports spawning habitats. There is also a need to identify other aquifers that may be important to the population. Installation of an observation well and mapping of groundwater extrusion into the lake will provide the information necessary to identify, protect and improve spawning habitat;
- **Migratory corridor**: There is uncertainty about adult migration behaviour throughout the freshwater corridor and the distribution of adults in the lake before spawning. We need to know more about those habitats in the mainstem Fraser adjacent to the Sumas/Fraser confluence, and in the Vedder and Chilliwack rivers and Sweltzer Creek. Activities along the migratory route, especially in the Sumas and Vedder-Chilliwack rivers and Sweltzer Creek, need to be evaluated to control those that may delay migration to the lake or expose the population to predation by marine mammals or poaching. The behaviour of adults after they enter the lake needs to be evaluated to determine whether they are vulnerable to any threats;
- **Land use patterns**: We need to know more about the impact of current land uses, and there is a need to model potential land uses and their impacts in order to protect habitat in the system;
- **Lake production dynamics and carrying capacity**: Lake productivity is an important component of the population's productive capacity. While known in a general sense through evaluations of photosynthetic rate, further assessment of the affects of competition, habitat limitation and predation, especially at current low spawner populations, is required. Such studies could also investigate the linkages between sockeye and other species in the freshwater ecosystem. An improved understand of lake productivity would help to qualify the role of depensation as a threat to the population and to set long term population abundance targets.

Predators and parasites

The relationship between sockeye fry and pikeminnow and the role of watermilfoil in providing pikeminnow refuge need to be better understood. We need to document the current distribution and abundance of predators and watermilfoil to enable us to develop long term, effective removal and assessment processes (see *Actions Already Completed or Under Way*) that will improve freshwater survival.

The impact of poaching and predation by marine mammals along the migratory corridor is unknown. An improved understanding would help guide conservation actions.

The impact of the copepod *Salmincola californiensis* on freshwater and marine survival is also unknown. A better understanding of the latter is important because the treatment of smolts is a potential conservation action.

Genetic trends

Trends in the population's genetic structure should be monitored continuously by sampling returning adults. Evaluations of fitness would benefit from comprehensive sampling, coordination with the hatchery program, and analysis of parentage and grand-parentage. The empirical effects of captive breeding have been little documented and an evaluation of this project could also benefit from DNA sampling and comparison with the wild population. This information will improve our assessment of population viability.

Marine distribution

The survival and distribution of Cultus sockeye in the Fraser River and near-shore marine areas have not been documented, nor has the distribution of the population in the North Pacific Ocean.

Achieving our Conservation Goal is biologically and technically feasible. Given its current status and the combined effects of low productivity, periodic declines in survival, high PSM and capture in the fishery, a conservation program will involve many sectors including government agencies, First Nations, researchers, managers, harvesters, NGOs and the public. It will involve a combination of actions to address threats to Cultus sockeye, including a significant building of awareness of the biological, social and cultural issues affecting the population.

BIOLOGICAL AND TECHNICAL FEASIBILITY

"Conservation of an endangered species or population depends greatly on the contributions of various sectors of society."

Biological feasibility

Biological feasibility depends on the intrinsic viability of the population. For Cultus sockeye, this essentially means its ability to increase and depends on its reproductive capability and society's ability and willingness to control or mitigate threats. Luckily, sockeye salmon have high biotic potential (high survival resulting in more adult offspring than in the parent generation), are relatively short lived (they mature, spawn and die at age 4 or 5), and are resilient to natural or human-induced pressures. However, Cultus sockeye is less productive than other Fraser River sockeye populations and has been intercepted in mixed-stock fisheries at greater than sustainable levels.

The Recovery Team assessed the biological feasibility of our Conservation Goal using a simulation model based on the historical stock-recruitment relationship. The model determines the minimum viable population (MVP) given a continued pattern of recent PSM and minimal harvest levels. Populations smaller than the MVP will have a significant risk of extinction even in the absence of human-caused mortality. The model makes several assumptions[3] and includes random variation in survival. It does not attempt to capture the dynamics of, or genetic effects associated with, very small population sizes.

The MVP estimate produced by this model is 250 successful adult spawners in any given year. The fact that this figure is below the current average per generation suggests that conservation is feasible. Moreover, because the estimate includes measurement error of catch assigned to Cultus and assumes pessimistic PSM values, populations smaller than 250 successful spawners in any year may still be viable. The possibility for genetic damage at these low abundances, however, was not modelled. Also, we noted simulation periods where single, double and triple cycle lines fell below 100 spawners. This suggests that minimum acceptable spawning levels should also be set for individual cycle lines, not just for each generation.

Technical feasibility

Technical feasibility reflects the availability of appropriate tools and the willingness of responsible organizations and jurisdictions to use them. Human-induced threats can be mitigated by government or stakeholder actions. For example, fishing can be modified or minimized through gear modifications, time and area closures, selective techniques and other actions. Recreational activities that affect adults in freshwater (*e.g.*, during their migration through Sweltzer Creek or in Cultus Lake itself) can also be modified.

While some natural impacts such as poor marine survival due to climatic variation cannot be mitigated directly, there are technical tools for reducing some of the natural threats to the Cultus population. For example, actions to improve freshwater survival by removing Eurasian watermilfoil, controlling predators or identifying and eliminating potential contamination are technically feasible. Hatchery technologies for captive breeding are also available.

[3] Extinction (technically termed *pseudo-extinction*) is defined as four consecutive years with <100 successful spawners, a number chosen because population dynamics are unknown at small abundances. MVP is defined as the initial number of adult spawners that keeps the extinction probability below 5% over 100 years with minimal exploitation and prescribed PSM. ERs up to 15% are considered because it may be impractical to prevent all fishing-related mortality (e.g., international treaty obligations, by-catch and test fisheries that occur over a wide geographic area and time period). PSM is stipulated because it is not controllable; a pessimistic scenario is that the 1995-2003 PSMs will persist. All other threats are assumed to be either controllable (e.g., Eurasian water milfoil) or subsumed in the historic stock-recruitment profile (e.g., pollution). The reliability of the MVP estimates depends on the assumption that stock recruitment estimated from historical 1948-1997 data can be applied to future spawning stocks. For example, climate change or recent changes in the stock-recruit function (i.e., ecological or genetic changes affecting productivity or carrying capacity) have not been considered.

Recommended Scale for Conservation

We recommend a single species conservation strategy for Cultus sockeye. This recommendation is based on the unique set of physical, biological and social circumstances surrounding the population. While there is currently one other B.C. sockeye population listed by COSEWIC as endangered (Sakinaw), the threats to the two populations are sufficiently different to warrant dedicated strategies for each. A multi-population strategy has, however, been adopted for a constellation of Interior Fraser coho salmon populations where genetics, geography and environment are more homogeneous.

Conservation of an endangered species or population depends greatly on the contributions of various sectors of society, which have a synergistic effect. Fortunately, the scale of conservation of Cultus sockeye can be broadened through cooperation. First, the importance of the salmon to First Nations means there should be close cooperation with the Soowahlie Band and the Sto:lo First Nation on all conservation activities. Second, administrative systems for the provincial and municipal Cultus Lake parks offer many opportunities for outreach, awareness and enforcement. Close contact with the Cultus Lake Park Board will need to be maintained. Third, management plans developed by DFO and the Fraser River Panel of the Pacific Salmon Commission represent the formal reflection of any conservation actions related to harvest; the population itself represents something of a test case of the principles of DFO's Wild Salmon Policy. Finally, involvement of the general public by way of stewardship groups that contribute to planning or take on some of the conservation activities will ensure that anyone passionate about Cultus sockeye will have the opportunity to contribute.

Conservation of Cultus sockeye will need to be coordinated with any actions developed for the endemic pygmy sculpin (*Cottus sp.*), presently listed by COSEWIC as *Threatened* and by the Province of B.C. as *Critically Imperiled* (Cannings *et al.* 1994). Watermilfoil removal will need to be coordinated with any provincial government policy on the control of this species.

CONSERVATION AND REBUILDING

"Small populations face unique risks."

The listing of species by COSEWIC reflects several kinds of information, including quantitative criteria developed by the International Union for the Conservation of Nature (IUCN; www.COSEWIC.gc.ca). Most relevant to Cultus sockeye are IUCN Criterion A ("declining total population"), Criterion C ("small total population size and decline") and Criterion D ("very small population or restricted distribution").

The science of conservation biology is intimately concerned with the concept of the MVP. Behaviour, reproductive biology and population genetics affect what this number will be, and there is a large literature on factors that need to be considered in determining MVPs for salmon. Above all, small populations face unique risks. For example, the following processes present little risk to large populations but pose much more of a problem for small populations like Cultus sockeye:

- Immediate threats such as density effects (*e.g.*, depensation – a decline in productivity that accelerates the population's decline, difficulty in finding a mate when there are few animals around, or increased effectiveness of predators as the prey population declines), random demographic effects (*e.g.*, a large imbalance in the sex ratio, or there being few survivors in a particular year even though environmental conditions are unchanged) and random environmental variation (*e.g.*, changes in ocean conditions or catastrophes like landslides); and
- Longer term threats such as genetic processes (*e.g.*, inbreeding depression and loss of variability), random demographic effects (*e.g.*, a large imbalance in the sex ratio, or there being few survivors in a particular year even though environmental conditions are unchanged) and ecological feedback (*e.g.*, important ecological functions like lake fertilization through carcass decomposition).

All of these processes must be taken into account when modeling the MVP for Cultus sockeye; if they are not, extinction risk will be underestimated. MVPs chosen for other species or in other jurisdictions provide useful comparisons:

- The number of Snake River chinook spawners required for the population to persist despite random environmental variation was estimated to be between 1,000 and 5,500 per generation (250-1,375 per year; NMFS 1995);
- Extinction risk from random demographic events increases exponentially as populations decline and should be considered a risk factor for any population of only a few hundred individuals (Goodman 1987);
- Genetic effects are dealt with by the concept of effective population size, which is usually smaller than the observed number of breeders (Frankham 1995). Allendorf *et al.* (1997) used genetic evidence to conclude that salmon populations with fewer than 2,500 spawners per generation would be at high risk where the effective population size is 20% of the number of breeders, a common assumption for Pacific salmon. The Washington Department of Fish and Wildlife (1997) recommended a minimum spawning size of 3,000 per generation.

Conservation Goal

Our goal is to halt the decline of the Cultus sockeye population and to return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.

Conservation Objectives

We identify four sequential objectives. Objective 1 secures genetic variability, Objective 2 ensures the population is growing, and Objective 3 achieves de-listing by COSEWIC – the change in designation from *Endangered* to *Not at Risk*.

Once the population is de-listed, conservation objectives should be consistent with (*i.e.*, not less than) those specified for other sockeye populations. Objective 4 proposes candidate benchmarks that correspond to our current understanding of the dynamics of Cultus sockeye.

Progress toward achieving all four objectives will be assessed annually by evaluating assessment data, by engaging local communities through workshops, websites and other media, and by recommending further studies required to address knowledge gaps.

Objective 1

Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful adult spawners with no fewer than 500 successful adult spawners on any one cycle.

Note 1 A *successful spawner* is one that fertilizes eggs (male) or deposits eggs (female). The number of successful spawners is based on fence counts and carcass recoveries from spawning ground surveys in the lake. Because success among males cannot readily be determined from the carcasses, the estimate of female success is applied to the entire population.

Note 2 The genetic consequences of small populations include the random loss of genetic and phenotypic variation and the loss of evolutionary potential associated with a reduction in genetic diversity (Allendorf and Ryman 2002). To avoid negative genetic impacts, population abundance must be maintained above the *minimum* genetically effective population size of 1,000 per generation. Applying conventional assumptions (Waples 2002) to the life history of Cultus sockeye, this implies that the average annual spawning abundance should exceed 1,000 fish, with no fewer than 500 spawners in any one year.

Note 3 How do the adults produced by the eight-year captive breeding project (see *Approaches to Meeting Conservation Objectives*) figure in this total? The number of successful Cultus sockeye spawners in any given year is deemed to include all naturally spawning sockeye, including the progeny of captive brood stock that have survived in the wild since their release as juveniles. However, adults collected as brood stock for artificial propagation will not be included in the estimate of successful spawners produced for that year.

Note 4 Although the target levels in Objective 1 eliminate genetic risk to the population (preserve genetic resources) and are adequate to avert listing under IUCN Criterion D, they are not adequate to avert listing under criteria A or C unless population abundance is increasing. De-listing should be assured by meeting the following objective (Objective 2).

Objective 2

Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years.

Note 1 The time series of spawner abundance information shows that generation size rarely increases unless there is cycle over cycle growth (*e.g.*, 1994 is bigger than 1990) on at least three of the four cycles. Historical records from 1930 to 2003 show a generation growth rate of 54% when growth occurred in three out of four years. Given the uncertainties in forecasts and in-season processes, managers should target growth on *all* cycles during the recovery phase to increase their likelihood of achieving positive generation-over-generation growth. If one or more of the previous three years declines, more stringent measures will be required to ensure positive growth in the current year.

A numeric target for population size and a time frame for achieving it would make it possible to establish growth rate targets for the population.

Objective 3

Rebuild the population to the level of abundance at which it can be de-listed (i.e., designated *Not at Risk*) by COSEWIC.

Note 1 COSEWIC uses the quantitative IUCN criteria as guidelines to assess the status of wildlife species in Canada. Because the IUCN criteria are not always appropriate for regional (*versus* global) application, COSEWIC also considers other biological characteristics and threats when designating species status. We acknowledge that such assessments and designations are COSEWIC's mandate. Here we provide advice for future COSEWIC reassessments in the context of the conservation goal for Cultus sockeye. For this population to be recovered, the following questions will have affirmative answers:

- *Have objectives 1 and 2 been achieved?* A recovered population must exceed the minimum abundances identified in Objective 1 and must have shown the growth in successive generations identified in Objective 2.
- *Have the causes of the decline identified by COSEWIC been addressed?* The COSEWIC status report identifies three principal causes: over-exploitation in fisheries, recruitment failure and high pre-spawn mortality. Regulatory agencies must develop short and long term management plans that include harvest rules and escapement policies for the sustainable use of Cultus sockeye. These plans must be consistent with the Team's goal and objectives and explicitly address uncertainties in population dynamics and management imprecision while protecting the population from unanticipated catastrophic PSM. The population must be able to withstand at least one cycle of poor environmental conditions without declining to a generation average of less than 1,000 successful spawners and 500 successful spawners on any cycle. This means managers must deliver a big enough escapement to the counting fence to achieve these population sizes on the spawning grounds. To do so, they must consider forecasting and in-season run size errors as well as uncertainty about PSM. For example, Objective 1 could be achieved despite 93% PSM (the most extreme ever observed) provided the management plan delivered an escapement of no fewer than 7,100 adults to the fence.

- *Is freshwater productivity adequate to support rebuilding?* Analysis of historical data provides some evidence that, when spawner abundance is less than about 7,000 fish, freshwater productivity is lower (20-30 smolts/spawner) than in years of higher abundances (>60 smolts/spawner; see *Biological Limiting Factors*). The low productivity at current abundances will limit the population's potential for conservation or sustainable use. An increase in productivity as the population rebuilds is, therefore, an important indicator.
- *Have emergency mitigative measures been relaxed?* A viable wild population would safely allow stopping supplementation and thereby eliminate it as a source of genetic risk or catastrophic failure. Such a population in its natural ecosystem would not require ongoing predator control measures. We note, however, that the productivity of predator populations may have increased as a result of the invasion of Eurasian watermilfoil. Consequently, plant or predator removal may need to continue.

Objective 4

Over the long term, rebuild the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use.

Note 1 This objective addresses ecosystem and sustainable use goals. Choosing an appropriate level of abundance requires the weighing of scientific advice in the context of broad policy objectives for salmon management which often must consider conflicting societal values. This target level of abundance must reflect the unique characteristics of the Cultus population and its ecosystems, *i.e.*, represent some reasonable proportion of the population's productive capacity. Setting the target level of abundance is beyond the Team's mandate and should be addressed by government policy-makers in consultation with the stakeholders. It is expected that the DFO's Wild Salmon Policy will provide an appropriate framework.

Note 2 The choice of a long-term target level of abundance must be based on our current understanding of the production dynamics of the Cultus population. Potential reference points include the following benchmarks, all of which are described in detail in Annex 2:

- The abundance providing maximum sustainable yield (S_{MSY}) or some proportion of S_{MSY};
- Some proportion of the productive capacity of the lake;
- Historic abundance; and
- The abundance at which ecosystem function is maintained.

Approaches to Meeting Conservation Objectives

Conservation and rebuilding of Cultus sockeye will be achieved by a set of actions that, working in concert, will maintain the population above a minimum level and allow generational growth. The Team provides the following approaches for consideration.

Control of exploitation

The Team believes that fishery exploitation will be possible during conservation and rebuilding when considered in the context of cycle-specific population sizes and the full suite of conservation actions selected. Controlling exploitation means developing short and long term harvest management plans that specify sustainable harvest rules and escapement policies for Cultus sockeye. These rules and policies must be consistent with the Team's goal and objectives, especially objectives 1 and 2, and explicitly address uncertainties in population dynamics as well as management imprecision.

Objective 1 *(Approach 1b)* will likely require extreme conservation measures if forecasts of returning adults are below 500. To address Objective 2 *(Approach 2b)*, managers need only to achieve positive generational growth. They have considerable latitude based on brood year strength, pre-season abundance forecasts, anticipated PSM levels and the degree to which they tolerate risk. Objective 3 *(Approach 3a)* requires an explicit statement of the short term plans described above in conjunction with explicit long term plans that fully address the Team's goal in the context of DFO's policy objectives. The Team notes that exploitation can be controlled not only through reductions or fishery closures but also through non-traditional fishery management measures that would permit the harvesting of co-migrating sockeye populations at times and in areas where Cultus sockeye are not present.

Maximizing freshwater survival

The control of predators (*Approach 1d*), including reduction of Eurasian watermilfoil (*Approach 1c*), could provide the increase in fry and smolt survival that is crucial to small juvenile populations such as those likely to result from the 2004 and 2005 brood years. Mossop *et al.* (2004) reviewed pikeminnow control projects from 1935-42 and in the 1990s (Hall 1992). They concluded that predator removal may be most effective if it targets specific areas and appropriate times, such as on the spawning grounds at the time of emergence and in the lake near Sweltzer Creek during the smolt migration. The latter may be most feasible and have the greatest benefit. They also recommend investigating pikeminnow predation during periods of low sockeye abundance and the impact of other predators, although they note that the removal of salmonid predators may no longer be socially acceptable.

Table 2. Summary of Approaches to the Conservation of the Cultus Sockeye Population

OBJECTIVE	APPROACH	THREAT	ANTICIPATED EFFECT	STATUS
1.	a. Captive brood stock program for 2000-2007 brood years.	Multiple	Increased successful spawners, reduced threat of extinction.	Under way
	b. Control harvest to achieve 1,000/500 objective.	5a	Increased successful spawners, reduced threat of extinction and of detrimental genetic effects.	Proposed
	c. Improve freshwater survival of 2004 and 2005 broods by removing watermilfoil.	2b, 6a	Reduced pikeminnow recruitment, decreased predation, increased number of sockeye smolts, increased spawning habitat.	Under way
	d. Improve freshwater survival of 2004 and 2005 broods by removing predators.	2a, 3c	Reduced predator populations, increased number of sockeye smolts.	Under way
	e. Identify the causes of the early migration phenomenon.	1c, 5b	Increased number of successful spawners.	Under way
	f. Focused enforcement where the population is most at risk.	5f	Increased number of successful spawners.	Proposed
	g. Identify imminent risks from habitat destruction, pollution affecting each life stage.	Multiple	Improved survival at all life stages.	Proposed
	h. Maintain assessments of fry, smolt and adult populations.	Multiple	Maintain ability to assess threats and recovery progress.	Under way
	i. Eliminate activities that cause migratory delay in Sweltzer Cr.	5c, 5d	Increased successful spawners.	Proposed
	j. Identify and eliminate risk from marine mammal predation.	5g	Increased number of adults through Sweltzer fence.	Proposed
2.	a. Lake stocking using fry, smolts surplus to the captive brood stock program during the period 2003 to 2009.	Multiple	Increased number of smolts, increased successful spawner populations, reduced genetic risk.	Under way
	b. Control fishery harvest to levels that permit generational growth.	5a	Increasing successful spawner populations.	Under way
	c. Develop an integrated water milfoil, predator control project.	5b, 6a, 2a, 3c	Maintain larger fry, smolt populations established by 1c and 1d.	Proposed
	d. Focused enforcement to reduce the threat of poaching.	5f	Increased number of successful spawners.	Proposed
	e. Mitigate effects on habitat.	Multiple	Improved survival at all life stages.	Proposed
	f. Determine the effects of Salmincola on marine survival.	2c, 3e	Increase marine survival, increased number of successful spawners.	Proposed
3.	a. Develop sustainable harvest rules and escapement policies that are consistent with Team goals and objectives and explicitly address uncertainties	5a	Maintain a viable, self-sustaining and genetically robust population over the long term.	Under way
	b. Evaluate freshwater productivity during recovery.	1a, 1d 2d, 2e	Improved understanding of threat to recovery posed by depensatory mortality, predator pit and habitat alteration.	Under way
4.	a. Identify the adult migration timing of Cultus relative to other Fraser Late Run sockeye.	n/a	Improved understanding of the stock-recruitment relationship may change approaches to recovery.	Proposed
	b. Identify the role and contribution of sockeye to the Cultus Lake ecosystem.	n/a	Improved long term population goal.	Proposed
5.	a. Promote stewardship and improve public awareness.	n/a	Increased public awareness and improved stewardship initiatives.	Under way

Key knowledge gaps that need to be filled to optimize predator control have already been discussed (see *Knowledge Gaps*).

Because freshwater productivity is key to the conservation of the Cultus population, further research is needed in areas that range from understanding how depensation *(Approach 3b)* and habitat degradation *(Approaches 1g, 2e)* contribute to current low smolt production rates to the ongoing assessment of adult abundance, PSM and smolt abundance *(Approach 1h)*. Details of these and other knowledge gaps related to population dynamics and utilization of freshwater habitat have already been provided (see *Knowledge Gaps*).

A demographic modelling approach will help identify and quantify important habitat. Such models are useful because they articulate the relationships between the population and its habitats, and Cultus is particularly suitable because of its long time series of assessment data that describe survival rates at different life stages.

Other approaches that are identified in *Knowledge Gaps* include the causes of early entry of adults into freshwater *(Approach 1e)*, the evaluation of activities along the migratory corridor that may delay the migration to the lake *(Approach 1i)*, and the control of predation by marine mammals *(Approach 1j)* and poaching *(Approaches 1f, 2d)*.

Maintaining assessments over the long term

The time series of assessment data for Cultus sockeye adults, fry and smolts is among the longest in existence for any Pacific salmon population. Keeping these assessments going will be essential for monitoring recovery of this population (*Approach 1h*).

Fish culture

Technical methods used for salmon conservation include habitat restoration, which provides habitat where fish can spawn and rear naturally, and techniques that involve greater human intervention in the actual acts of spawning and rearing. For Cultus sockeye, an example of habitat restoration is the removal of watermilfoil from spawning beaches. An example of the second, more intensive kind of intervention is fish culture. Results of the Cultus Lake sockeye fish culture program are summarized in Table 3.

Fish culture methods include *conventional supplementation* and *captive breeding*; the key difference lies in the length of time in captivity. Conventional supplementation (*Approach 2a*) uses hatcheries to incubate fertilized eggs taken from returning adults, after which juveniles are released to the wild as fry or smolts. The fish then grow and mature in the ocean and return to spawn in natural habitats in the system from which they originated, thus integrating with and contributing to the conservation or maintenance of the wild population. Key practices such as the use of native spawners, prescribed spawner collection methods and spawning practices, and evaluation of subsequent survival help to maintain the genetic characteristics of the parent wild population.

A captive breeding project (*Approach 1a*) is a more intensive method that rears captured wild juveniles or the progeny of hatchery-spawned parents in captivity, all the way to their own maturation and spawning. *Their* progeny are then released to the wild. The main features of this method are the enormous increase in egg-to-adult survival (more than a thousand-fold), thereby permitting the rapid recovery of the population, and the increased potential for domestication selection (including the effects of relaxed natural selection). Such projects are usually regarded as methods of last resort, an experimental approach to be used only as part of an integrated plan in situations where the natural population is at risk of extirpation. Although specific concerns have been expressed about the potential genetic and environmental drawbacks of captive breeding, including the risk of domestication selection (Allendorf and Ryman 1987; Waples 1999), most of these (except domestication selection) can be alleviated by carefully designed mating strategies (Hard *et al.* 1992). In the case of Cultus sockeye, genetic concerns about a small founder population (potential inbreeding depression leading to loss of genetic diversity) are alleviated by using a breeding plan that actually increases genetic diversity. The increased survival inherent in captive brood programs also decreases the potential loss of genetic diversity in hatchery fish compared to wild fish.

Emerging DFO policies for the use of captive breeding include limiting the technology to the conservation of endangered populations, the use of mating strategies that minimize the potential loss of genetic variability in captivity and the use of the technology for no longer than is necessary to fulfill stated conservation goals to minimize domestication selection (C. Cross 2004, pers. comm.).

The following guidelines apply to Cultus sockeye:

- The objective is to produce 500 breeding adults each year for two consecutive cycles (eight years), followed by a full review of the program in 2007;
- Only wild spawners will be used, and those fish will not be counted as part of the naturally breeding population when evaluating progress;
- When adults produced from the captive spawners are themselves spawned in captivity, they will not be counted as part of the natural breeding population. However, their progeny that are released into the wild and return to spawn naturally will be included;
- All fish produced in the program and released to the wild will be marked with an adipose fin clip. An awareness program will ensure that anglers understand the difference between a marked sockeye (which must be released) and a marked coho (which can be retained).

There are operational risks associated with hatcheries, including the possibility of mechanical failure and disease. Preventive measures include culturing Cultus sockeye at two facilities (Inch Creek and Rosewall Creek), redundant water deliver systems, emergency response readiness (standby staff), site security and operational protocols that minimize disease outbreaks. Furthermore, hatchery managers are authorized to acquire eggs in excess of those required to produce 500 spawners under average survival conditions. Any production above the needs of the captive breeding project is planted in the lake as fry or smolts to supplement the wild population. Thus, in the case of Cultus sockeye, supplementation and captive breeding work together.

Community awareness
The present status of the population means that good stewardship is vital. Residents, park visitors, farmers, businesses and resource industries in the watershed need to understand the fragile state of Cultus sockeye and be prepared to do their part in promoting conservation. Also, a special effort needs to be made to ensure that recreational anglers are aware of conservation issues that set Cultus sockeye apart from other species and stocks. Partners interested in raising awareness are needed to work with all stakeholders represented on the Recovery Team *(Approach 5a)*.

Potential Impacts of the Conservation Strategy on Other Species

The impacts of conservation actions on other species and ecological processes need to be identified and prevented, particularly for the threatened Cultus pygmy sculpin. The pygmy sculpin is a small, relatively abundant fish (populations of 3,000-10,000). It lives in the deeper parts of the lake where it feeds on zooplankton and other fish and is preyed on by char (Coffie 1997). There are few known conflicts between pygmy sculpins and the conservation of Cultus sockeye. The selection of prey species appears sufficiently specialized to avoid direct competition; a recovered sockeye population may "swamp" char populations and reduce predation on the sculpins; and the focus of conservation activities along the shore means that most of them (*e.g.*, watermilfoil removal or predator control) will not affect the sculpins.

Actions Already Completed or Under Way

Population assessment *(Approach 1h)*
Population assessment focuses on the fry, smolt and adult life stages. Fry are assessed in the fall using hydro-acoustic and mid-water trawl surveys to produce estimates of population size and, recently, fin clip or calcein (Negus and Tureson 2004) incidence. These data are useful in evaluating survival bottlenecks in Cultus Lake.

Assessments at the counting fence in the spring provide data on numbers of wild and enhanced smolts as well as on smolt size and the incidence of parasites. This information is used to assess freshwater and marine survival, the success of enhancement strategies and predator removal experiments and possibly the impact of parasites if wild and enhanced smolts have different levels of infestation. Under extreme PSMs, smolt data can also serve as an alternate assessment of PSM.

Adults are assessed in the fall and winter at the counting fence, which is now continuously monitored to reduce migratory delays, mitigate predator threats and acquire brood stock for captive breeding, and by spawning ground surveys conducted by foot, boat or underwater video. Sweltzer Creek is patrolled at least twice weekly to identify and eliminate sources of migratory delay. The assessment provides counts of wild and enhanced adults and jacks, spawner size, sex and spawning success and spawner distributions. The information is used to assess marine survival, enhancement strategies and PSM, and to forecast future abundance.

Fish culture *(Approaches 1a, 2a)*
The captive breeding and supplementation projects (see *Approaches to Meeting Conservation Objectives*) have been under way since 2000; progress is described in Annex 3 and is summarized in Table 3. A supplementary project has been the *ex situ* collection of cryopreserved sperm that began in 1995 and has continued as part of the captive breeding project. This collection provides an historic record of genetic variability in the 2003 cycle.

Agency: DFO

Early migration/high mortality *(Approach 1e)*
Of the several competing hypotheses to explain early migration, two are presently being studied: a behavioural hypothesis that late run sockeye become caught up in numerically much larger summer run populations, and a physiological hypothesis that early entry into freshwater is related to unusual kidney and osmoregulatory function linked with low salinity plumes in coastal waters.

The first hypothesis is being investigated through analysis of historic run size and timing data. The second was the focus of most of the work in 2004-05. Most of the physiological research on the second hypothesis is through a multi-university, multi-agency research project funded through the Natural Sciences and Engineering Research Council of Canada. DFO is contributing personnel and facilities at their Cultus Lake and West Vancouver laboratories, and the Pacific Salmon Commission is providing staff, sockeye from test fisheries and vessel time. Previous studies suggest that high freshwater mortality is caused by *Parvicapsula*-induced osmoregulatory malfunction, and by high water temperature which hastens the depletion of energy reserves. Early-entering fish have poorer blood clotting ability, poorer swimming performance and higher *en route* mortality close to spawning grounds than do those entering at the normal time. Accumulated exposure to elevated temperature affects the severity of the *Parvicapsula* infection and mortality rates, and *Parvicapsula* may reduce the survival rates of fertilized eggs.

In 2004, researchers investigated the reasons for the onset of early migration and its immediate and inter-generational consequences. They examined migration behaviour and linkages with physiological state as well as the behavioural energetics of spawning and swimming performance in relation to disease and temperature.

Agencies: UBC/DFO/PSC

Aquifer assessment *(Approach 1g)*
A project is under way to determine whether water withdrawal from the Columbia Valley aquifer could affect spawning habitat.

Agencies: DFO, Lindell Beach Residents' Association

Assessment of littoral habitat *(Approaches 1c, 1g, 4b)*
A project is underway to identify, characterize and map spawning habitat, Eurasian watermilfoil distribution and groundwater sources. The project has three components:

- Dominant vegetation and substrates in the littoral zone have been mapped using a towed dive sled. This information has been used to identify potential spawning habitat and to develop a strategic watermilfoil control strategy for implementation in 2005;
- Water quality and groundwater assessments were conducted in the winter of 2005;
- The results of acoustic surveys of the littoral zone will be compared to underwater visual survey results to identify a cost-effective strategy for the annual monitoring and removal of watermilfoil;
- A milfoil removal project to have begun in early 2005 has been delayed until later in the year.

Agencies: DFO, Cultus Lake Park Board, B.C. Parks, Lindell Beach Residents' Association.

Impact of pikeminnow predation *(Approaches 1d, 2c)*
A project is being carried out to improve our understanding of the predation threat and produce a strategy to combat it. The project has four components:

- The development of a predation model based on the literature review conducted in the spring of 2004 (Mossop *et al.* 2004) that will be used to develop a long term predator control strategy;
- A population estimate for adult pikeminnow was made based on a mark and recapture program conducted in 2004 and 2005 which resulted in an estimate of 60,000–70,000 pikeminnow in the lake in 2004.
- Various means of removal have been conducted since 2005, including trapping, angling, community-based derbies and, most significantly, a commercial fishing boat with a large seine net. By 2006, over 20,000 adult pikeminnow have been removed from the lake. The seiner will continue its operations in 2007.

Agencies: DFO, Fraser Valley Salmon Society.

Table 3. Summary of Enhancement Results, Captive Breeding and Supplementation Projects

Brood year	2000	2001	2002	2003	2004	2005	2006
Adults captured							
male	n/r	n/r	89	105	17	85	103
female	n/r	22	177	141	20	63	168
Adults spawned							
male	10	11	70	100	15	78	76
female	5	9	120	132	10	60	121
eggs taken	13,385	24,458	438,100	464,038	39,976	185,273	430,674
Brood year +1							
fry release[a]	0	3,715	227,029	346,002	21,384	99,727	350,000[d]
year-end balance	3,892	1,880	3,296	53,406	2,691	52,061	53,000[d]
Brood year +2							
smolt capture[b]	2,014	881	0	0	0	0	-
smolt release[a]	3,891	3,166	2,135	47,804	53,760	53,150	-
number spawned	0	184	9	0	0	0	-
eggs taken[c]	0	16,000	0	0	0	0	-
year-end balance	1,070	1,564	738	451	1,303	0	-
Brood year +3							
number spawned	89	515	178	561	-	-	-
eggs taken[c]	46,000	694,058	256,512	813,291	-	-	-
year-end balance	928	401	241	380	-	-	-
Brood year +4							
number spawned	205	138	83	-	-	-	-
eggs taken[c]	631,677	233,638	146,597	-	-	-	-

[a] supplementation
[b] captive brood augmented for genetic purposes
[c] captive breeding production
[d] estimated April, 2007

Marine survival and timing *(Approach 2f)*
The level of infection of *Salmincola* will continue to be recorded at two sampling points: during mid-water trawl assessments of fry abundance, and during the smolt emigration at the counting fence. The smolts retained for captive breeding are also treated orally and through the physical removal of parasites. Although treatment causes about 10% mortality it is necessary for the production of healthy fish. Because of the observed level of mortality, there are no plans to similarly treat wild smolts until the parasite is proven to be a threat to marine survival and timing.

In a more general assessment of in-river and early marine distributions and survival, acoustic tags applied to 100 smolts in the spring of 2004 were tracked as they passed through detection arrays in the lower Fraser River and along the coast as part of the Pacific Ocean Shelf Tracking (POST) project (Welch *et al.* 2003). This type of tag remains active for about 120 days before complete battery failure. Results for 2004 are posted at www.postcoml.org. In 2005, the project expanded to 700 smolts and utilized tags with the capacity to transmit during the return migration in 2007, permitting assessment of the timing of the return to Cultus in relation to other populations.

Agencies: DFO, Vancouver Aquarium Marine Science Centre

Control of exploitation *(Approaches 1b, 2b, 3a)*
Pre-season management planning: Fisheries that incidentally intercept Cultus sockeye were not managed with the explicit object of controlling the exploitation rate on Cultus sockeye until 2004. In prior years, however, the population benefited from measures to conserve Fraser late run populations in general. Since 1998, management plans have focused on the harvest of summer run populations but have also responded to concerns about the early migration and high PSM of late run populations by taking measures to reduce ERs (Schubert *et al.* 2002):

- In 1998-2000, while no specific guidelines were established for the harvest of late run sockeye, restrictions on fishing during August and September resulted in ERs of 19%, 13% and 44% respectively;
- In 2001-2003, specific guidelines were established to limit late run ERs to 17% in 2001 and 15% in 2002. In 2002, managers also excluded from the ER calculation any late run sockeye caught in the Fraser River before August 17;
- In 2003, fisheries were managed to an ER of 25% based on pre-season expectations of late run timing and abundance.

Marine survival and timing *(Approach 2f)*
The level of infection of *Salmincola* will continue to be recorded at two sampling points: during mid-water trawl assessments of fry abundance, and during the smolt emigration at the counting fence. The smolts retained for captive breeding are also treated orally and through the physical removal of parasites. Although treatment causes about 10% mortality it is necessary for the production of healthy fish. Because of the observed level of mortality, there are no plans to similarly treat wild smolts until the parasite is proven to be a threat to marine survival and timing.

In a more general assessment of in-river and early marine distributions and survival, acoustic tags applied to 100 smolts in the spring of 2004 were tracked as they passed through detection arrays in the lower Fraser River and along the coast as part of the Pacific Ocean Shelf Tracking (POST) project (Welch *et al.* 2003). This type of tag remains active for about 120 days before complete battery failure. Results for 2004 are posted at www.postcoml.org. In 2005, the project expanded to 700 smolts and utilized tags with the capacity to transmit during the return migration in 2007, permitting assessment of the timing of the return to Cultus in relation to other populations.

Agencies: DFO, Vancouver Aquarium Marine Science Centre

Control of exploitation *(Approaches 1b, 2b, 3a)*
Pre-season management planning: Fisheries that incidentally intercept Cultus sockeye were not managed with the explicit object of controlling the exploitation rate on Cultus sockeye until 2004. In prior years, however, the population benefited from measures to conserve Fraser late run populations in general. Since 1998, management plans have focused on the harvest of summer run populations but have also responded to concerns about the early migration and high PSM of late run populations by taking measures to reduce ERs (Schubert *et al.* 2002):

- In 1998-2000, while no specific guidelines were established for the harvest of late run sockeye, restrictions on fishing during August and September resulted in ERs of 19%, 13% and 44% respectively;
- In 2001-2003, specific guidelines were established to limit late run ERs to 17% in 2001 and 15% in 2002. In 2002, managers also excluded from the ER calculation any late run sockeye caught in the Fraser River before August 17;
- In 2003, fisheries were managed to an ER of 25% based on pre-season expectations of late run timing and abundance. On August 22, after the cessation of commercial fishing, the ER objective was reduced to 15% based on in-season revisions to estimates of abundance, migration timing and en route mortality. The application of these guidelines in 2003 resulted in the closure of all commercial sockeye fisheries in mid-August and in sockeye non-retention fisheries directed at pink salmon in late August and September. Late run ERs in 2001-2003 were 18%, 17% and 33%, respectively;
- In 2004 and 2005, the management planning and in-season processes established ER limits of 10-12% for Cultus sockeye. The actual ER for Cultus sockeye was 24%; in 2005 it was 7%.

Long term management planning: DFO is developing a formal framework for considering conservation and management objectives for Fraser sockeye. The new process (the Fraser River Sockeye Spawning Initiative) includes senior representatives from First Nations, the commercial fishing industry, recreational fishing, environmental non-government organizations, and the provincial and federal governments.

The initiative has several goals:

- Ensure conservation while respecting social and economic values;
- Improve consultation processes through proactive stakeholder discussion of targets and implementation guidelines rather than reactive, in-season decision making;
- Develop reference points and escapement policies for Fraser sockeye;
- Develop implementation guidelines to achieve long-term spawning objectives, including appropriate in-season adjustment mechanisms; and
- Develop processes for reviewing and modifying the targets, reference points and guidelines.

The initiative will initially develop a long-term escapement strategy and management reference points for 15 representative populations (including Cultus) from the four run-timing groups. This result will serve as a template for escapement strategies and management reference points for all Fraser sockeye populations. The new method for setting spawning escapement targets was to be implemented in 2005 and reviewed through consultation in 2006.

Fishery assessment: A management boundary near the Sumas River mouth has been established to help reduce interception of Cultus sockeye in Fraser River First Nations and recreational fisheries. In 2004, the effectiveness of that boundary was to be evaluated by genetic and other sampling in upstream fisheries.

Agencies: DFO, PSC.

Community awareness *(Approach 5a)*
A number of initiatives are underway to raise local awareness of the status of Cultus sockeye. Community meetings sponsored by DFO and the Soowahlie Band were held in November 2001 and July 2003; such meetings will continue intermittently. Other specific community awareness activities include:

- A brochure detailing the status of Cultus sockeye was printed and distributed in 2004;
- The Soowahlie Band is distributing information during fishery assessments and other projects to raise the awareness of residents and recreational fishers;
- Notices have been posted throughout the Cultus and Chilliwack areas to raise awareness regarding the status of the population and the difference between adipose-clipped sockeye and coho salmon; and
- Permanent information kiosks have been constructed at key sites around Cultus Lake, detailing the state of Cultus sockeye and describing how the public can assist in conservation.

Agencies: DFO, Soowahlie Band.

Evaluation

The rebuilding of Cultus sockeye must be evaluated annually from two perspectives: conservation plan implementation and actual biological recovery. As the lead jurisdiction, Fisheries and Oceans Canada will lead the annual evaluation in consultation with the appropriate species experts and stakeholders. The evaluation must include the broad performance measures described below.

The first and most obvious performance measure is the extent to which the conservation goal and objectives have been achieved:

- For the Conservation Goal: Has the population decline been halted? Has the pattern of change in genetic diversity and population structure improved?
- For Objective 1: Has the population exceeded an arithmetic mean of 1,000 successful adult spawners over the most recent four years? Has the population remained larger than 500 successful adult spawners in each year of the conservation plan?
- For Objective 2: Has there been growth of the successful adult spawner population for each generation? Has there been cycle over cycle growth for not less than three of the last four consecutive years?
- For Objective 3: Did the most recent annual management plan ensure the genetic integrity of the population and allow it to grow? Did it explicitly address uncertainties in population dynamics and management imprecision? Has freshwater productivity increased to historic levels?
- For Objective 4: Has DFO engaged stakeholders in a process to establish population objectives that address ecosystem and sustainable use goals?

Other important performance measures are the extent to which stakeholders have been consulted or involved in conservation and the success of public outreach, awareness and education programs. Indicators are numbers of meetings, partners engaged in projects, volunteer hours, information pamphlets distributed, media articles etc.

LITERATURE CITED

Allison, L.N., and Latta, W.C. 1969. Effects of gill lice (*Salmincola edwardsii*) on brook trout (*Salvelinus fontinalis*) in lakes. Mich. DNR Inst. Fish. Res. Rep. 1761.

Allendorf, F., Bayles, D., Bottom, D.L., Currens, K.P., Frissell, C.A., Hankin, D., Lichatowich, J.A., Nehlsen, W., Trotter, P.C., and Williams, T.H. 1997. Prioritizing Pacific salmon stocks for conservation. Conservation Biology 11: 140-152.

Allendorf, F.W., and Ryman, N. 2002. The role of genetics in population viability analysis. Pages 50-85 In: S.R. Beissinger and D.R. McCullough (eds.). Population Viability Analysis. The University of Chicago Press, Chicago, IL.

Beacham, T.D., Lapointe, M, Candy, J.R., McIntosh, B., MacConnachie, C., Tabata, A., Kaukinen, K., Deng, L., Miller, K.M., and Withler, R.E. 2004. Stock identification of Fraser River sockeye salmon using microsatellites and major histocompatibility complex variation. Trans. Am. Fish. Soc., in press.

Beamish, R.J., C. Mahnken, and Neville, C.M. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. ICES J. Mar. Sci. 54: 1200-1215.

Bevelhimer, M.S., and Adams, S.M. 1993. A bioenergetics analysis of diel vertical migration by kokanee salmon, *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. 50: 2236-2249.

Brannon, E.L. 1965. Observations of sockeye salmon in Cultus Lake. Int. Pac. Sal. Fish. Comm., unpublished. 5 p.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing. Pages 120-124 In: H.D. Smith, L. Margolis, and C.C. Wood (eds.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Brown, K.L., and Flack, C. 2004. Cultus Lake sockeye TEK project. Unpublished report to the Cultus Sockeye Recovery Team. 41 p.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). *In:* C. Groot, and L. Margolis, (eds.). Pacific salmon life histories. UBC Press, Vancouver, Canada.

Caddy, J.F. and Mahon, R. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper 347.

Cannings S.G., Fraser, D., and Munro, W.T. 1994. Provincial lists of species at risk. Pp. 16-23 In: L.E. Harding and E. McCullum, (eds.). Biodiversity in British Columbia. Canadian Wildlife Service, Delta, B.C.

Cass, A.J., and Wood, C.C. 1994. Evaluation of the depensatory fishing hypothesis as an explanation for population cycles in Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 51: 1839–1854.

Coffie, P. 1997. COSEWIC status report on the Cultus pygmy sculpin, *Cottus sp.* Committee on the Status of Endangered Wildlife in Canada. 11 p.

Cooke, S.J., Hinch, S.G., Farrell, A.P., Lapointe, M., Healey, M., Patterson, D., MacDonald, S., Jones, S., and Van Der Kraak, G. 2004. Early-migration and abnormal mortality of late-run sockeye salmon in the Fraser River, British Columbia. Fisheries 29(2): 22-33.

COSEWIC 2003. COSEWIC assessment and status report on the sockeye salmon *Oncorhynchus nerka* (Cultus population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 57 pp.

Cox-Rogers, S., Hume, J.M.B., and Shortreed, K.S. 2003. Stock status and lake-based production relationships for wild Skeena River sockeye salmon. PSARC Working Paper S2003-09.

Downing, J. A., Plante, C., and Lalonde, S. 1990. Fish production correlated with primary productivity, not the morphoedaphic index. Can. J. Fish. Aquat. Sci. 47: 1929-1936.

Fee, E. J., Stainton, M.P., and Kling, H.J. 1985. Primary production and related limnological data for some lakes of the Yellowknife, NWT area. Can. Tech. Rep. Fish. Aquat. Sci. 1409.

Foerster, R.E. 1968. The sockeye salmon (*Oncorhynchus nerka*). Fisheries Research Board of Canada Bulletin 162: 422 p.

Foerster, R.E., and Ricker, W.E. 1941. The effect of reduction of predaceous fish on survival of young sockeye salmon at Cultus Lake. J. Fish. Res. Bd. Can. 5 (4): 315-336.

Frankham, R. 1995. Conservation genetics. Annu. Rev. Genetics 29: 305-327.

Fraser Basin Council. 2002. Fish and wildlife indicator concept paper. Unpublished discussion paper released 28-August. 4 p.

Friesen, T.A., and Ward, D.L. 1999. Management of northern pikeminnow and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. N. Am. J. Fish. Manage. 19: 406-420.

Gall, G.A.E., McClendon, E.L., and Schafer, W.E. 1972. Evidence on the influence of the copepod (*Salmincola californiensis*) on the reproductive performance of a domesticated strain of rainbow trout (*Salmo gairdneri*). Trans. Am. Fish. Soc. 101: 345-346.

Gardner, J., and Peterson, D.L. 2003. Making sense of the salmon aquaculture debate: analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Prepared for the Pacific Fisheries Resource Conservation Council. Vancouver, B.C.

Gilhousen, P. 1992. Estimation of Fraser River sockeye escapements from commercial harvest data, 1892-1944. International Pacific Salmon Fisheries Commission, Bulletin XXVII.

Goodman, D. 1987. The demography of chance extinction. Pages 11-34 in M. E. Soulé, ed. Viable populations for conservation. Cambridge University Press, Cambridge, U.K.

Gulland, J. A. 1983. Fish stock assessment: a manual of basic methods. Wiley Interscience, Chichester, U.K.

Hall, D.L. 1992. Summary of the 1991 and 1992 squawfish removal program, Cultus Lake British Columbia. Unpublished manuscript. 30 p.

Hard, J.J., Jones, Jr., R.P., Delarm, M.R., and Waples, W.S. 1992. Pacific salmon and artificial propagation under the Endangered Species Act. U.S. Department of Commerce, National Marine Fisheries Service, Technical Memorandum NMFS-NWFSC-2, Seattle, WA.

Hinch, S.G., and Bratty, J.M. 2000. Effects of swim speed and activity pattern on success of adult sockeye salmon migration through an area of difficult passage. Trans. Am. Fish. Soc. 129: 604-612.

Hume, J.B., Shortreed, K.S., and Morton, K.F. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53: 719-733.

Johnson K.A., and Heindel, J.A. 2001. Efficacy of manual removal and ivermectin gavage for control of *Salmincola californiensis* (Wilson) infestation of chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), captive brood stocks. J. Fish Dis. 24: 197-203.

Johnston, N.T., Parkinson, E.A., Tautz, A.F., and Ward, B.R. 2002. Biological Reference Points from Deterministic Stock-Recruit Relations. B.C. Fisheries Branch. Fisheries Project Report No. RD100.

Jones, J. R., and Hoyer, M.V. 1982. Sportfish harvest predicted by summer chlorophyll-a concentration in midwestern lakes and reservoirs. Trans. Am. Fish. Soc. 111: 176 179.

Kabata, Z., and Cousens, B. 1977. Host-parasite relationships between sockeye salmon, *Oncorhynchus nerka*, and *Salmincola californiensis* (*Copepoda: Lernaeopodidae*). J. Fish. Res. Bd. Can. 34: 191-202.

Knudsen, E.E. 1999. Managing Pacific salmon escapements: the gaps between theory and reality. U.S. Geological Survey, Anchorage, Alaska.

Koenings, J.P., and Burkett, R.D. 1987. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density and forage base within Alaskan lakes. Pages 216-234 In: H.D. Smith, L. Margolis, and C.C. Wood [eds.]. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Koenings, J.P. and Kyle, G.P. 1997. Consequences of juvenile sockeye salmon and the zooplankton community resulting from intense predation. Alaska Fishery Research Bulletin 4: 120-135.

Leach, J. H., Dickie, L.M., Shuter, B.J., Borgmann, U, Hyman, J., and Lysack, W. 1987. A review of methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg. Can. J. Fish. Aquat. Sci. 44: 471-485.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences 51: 110-122.

Mace, P., and Sissenwine, M. 1993. How much spawning per recruit is enough? In S.J. Smith, J.J. Hunt and D. Rivard (eds.). Risk evaluation and biological reference points for fisheries management. Can. Spec. Publi. Fish. Aquat. Sci. 120: 101-118.

Marmorek, D.R., Parnell, I.J., and Mawani, T. 2004. Summary report of the salmon recovery technical workshop on Cultus Lake sockeye, Sakinaw Lake sockeye and Interior Fraser coho, April 29, 2004. Renaissance Hotel, Vancouver, B.C. Prepared by ESSA Technologies Ltd. For Fisheries and Oceans Canada. 42 pp.

Mossop, B., and Bradford, M.J. 2004. Review of Eurasian watermilfoil control at Cultus Lake and recommendations for future removals. Unpublished report prepared for the Cultus Sockeye Recovery Team. 26 p.

Mossop, B., Bradford, M.J., and Hume, J. 2004. Review of northern pikeminnow (*Ptychocheilus oregonensis*) control programs in western North America with special reference to sockeye salmon (*Oncorhynchus nerka*) production in Cultus Lake, British Columbia. Report prepared for the Cultus Sockeye Recovery Team. Vancouver. 58 p.

Mueller, C.W., and Enzenhofer, H.J. 1991. Trawl catch statistics in sockeye rearing lakes of the Fraser River drainage basin: 1975-1985. Can. Data Rep. Fish. Aquat. Sci. No. 825.

Naiman, R.J., Bilby, R.E., Schindler, D.E., and Helfield, J.M. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. Ecosystems. 5: 399–417.

Negus, M.T., and Tureson, F.T. 2004. Retention and non-lethal external detection of calcein marks in rainbow trout and chinook salmon. North American Journal of Fisheries Management 24: 741-747.

Newroth, P.R. 1993. Application of aquatic vegetation identification, documentation, and mapping in Eurasian watermilfoil control projects. Lake and Reserv. Manage. 7: 185-196.

NMFS. 1995. Proposed Recovery Plan for the Snake River. National Marine Fisheries Service, March, 1995.

Oglesby, R.T. 1977. Relationship of fish yield to lake phytoplankton standing crop, production, and morphometric factors. J. Fish. Res. Bd. Can. 34: 2271-2279.

Peterman, R.M., and Gatto, M. 1978. Estimation of the functional responses of predators on juvenile salmon. J. Fish. Res. Board Can. 35: 797-808.

PFRCC. 2003. Advisory: wild salmon and aquaculture in British Columbia. Pacific Fisheries Resource Conservation Council, Vancouver, B.C.

Restrepo, V.R., and Powers, J.E. 1999. Precautionary control rules in US fisheries management: specification and performance. ICES J. Mar. Sci. 56: 846-852.

Richards, L.J. and J.-J. Maguire. 1998. Recent international agreements and the precautionary approach: new directions for fisheries management science. Can. J. Fish. Aquat. Sci. 55: 1545-1552.

Ricker, W.E. 1933. Destruction of sockeye salmon by predatory fishes. Biol. Bd. Canada, Pacific Prog. Rept. No. 18, 3-4.

Ricker, W.E. 1937a. Physical and chemical characteristics of Cultus Lake, British Columbia. J. Biol. Bd. Can. 3 (4): 363-402.

Ricker, W.E. 1937b. Increasing the survival rate of young sockeye salmon by removing predatory fishes Fisheries Research Board of Canada Progress Reports of the Pacific Biological Station Nanaimo, B.C. and Pacific Fisheries Experimental Station Prince Rupert, B.C. No. 32.

Ricker, W.E. 1938. "Residual" and kokanee salmon in Cultus Lake. J. Fish. Res. Bd. Can. 4(3): 192-218.

Ricker, W.E. 1941. The consumption of young sockeye salmon by predaceous fish. J. Fish. Res. Bd. Can. 5 (3): 293-313.

Ricker, W.E. 1959. Additional observations concerning residual sockeye and kokanee (Oncorhynchus nerka). J. Fish. Res. Bd. Canada 16(6): 897-902.

Ryder, R. A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94: 214-218.

Schmidt, D.C., Carlson, S.R., Kyle, G.B., and Finney, B.P. 1998. Influence of carcass-derived nutrients on sockeye salmon productivity of Karluk Lake, Alaska: importance in the assessment of an escapement goal. N. Amer. J. Fish. Man. 18: 743-763.

Schubert, N.D., Beacham, T. D., Cass, A.J., Cone, T.E., Fanos, B.P., Foy, M., Gable, J.H., Grout, J.A., Hume, J.M.B., Johnson, M., Morton, K.F., Shortreed, K.S., and Staley, M.J. 2002. Status of Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Canadian Science Advisory Secretariat Research Document 2002/064: 109 p.

Shortreed, K.S., Costella, A.C., and Stockner, J.G. 1984. Periphyton biomass and species composition in 21 B.C. lakes: Seasonal abundance and response to whole-lake nutrient additions. Can. J. Bot. 62: 1022-1031.

Shortreed, K.S., Hume, J.M.B., and Stockner, J.G. 2000. Using photosynthetic rates to estimate the juvenile sockeye salmon rearing capacity of British Columbia lakes. Pages 505-521 In: E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser (eds.). Sustainable fisheries management: Pacific salmon. CRC Press LLC.

Shortreed, K.S., Morton, K.F., Malange, F., and Hume, J.M.B. 2001. Factors limiting juvenile sockeye production and enhancement potential for selected B.C. nursery lakes. Can. Stock. Ass. Sec. Res. Doc. 2001/098.

Stockner, J.G. 1987. Lake fertilization: the enrichment cycle and lake sockeye salmon (*Oncorhynchus nerka*) production. Pages 198-215 In: H.D. Smith, L. Margolis, and C.C. Wood [eds.]. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Sutherland, D.R., and Wittrock, D.D. 1985. The effects of *Salmincola californiensis* (Copepoda: Lernaeopodidae) on the gills of farm-raised rainbow trout, *Salmo gairdneri.* Can. J. Zool. 63: 2893-2901.

Urban Systems. 2003. Cultus Lake Park financial sustainability and governance alternatives Phase 1. Final report to the Joint Committee of the Cultus Lake Park Board, City of Chilliwack and Fraser Valley Regional District. 49 p.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83.

Walters, C.J. and M. Staley. 1987. Evidence against the existence of cyclic dominance in Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. Sp. Publ. Fish. Aquat. Sci. 96: 375–84.

Waples. R. S. 2002. Pacific salmon require special Ne calculation: Effective size of fluctuating salmon populations. Genetics 161: 783-791.

Waples, R.S. 1999. Dispelling some myths about hatcheries. Fisheries 24: 12-21.

WDFW. 1997. Final environmental impact statement for the wild salmonid policy. Washington Department of Fish and Wildlife, Olympia, Washington. 133 p.

Welch, D.W., Boehlert, G.W., and Ward, B.R. 2003. POST-the Pacific Ocean Salmon Tracking Project. Oceanologica Acta. 25: 243-253.

Withler, R.E., Le, K.D., Nelson, R.J., Miller, K.M., and Beacham, T.D. 2000. Intact genetic structure and high levels of genetic diversity in bottlenecked sockeye salmon (*Oncorhynchus nerka*) populations of the Fraser River, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 57: 1985-1998.

Wood, C.C. 1995. Life history variation and population structure in sockeye salmon. Pages 195-216 *In:* J.L. Neilsen (ed.) Evolution and the aquatic ecosystem: defining unique units in popula' 'on conservation. American Fisheries Society Symposium 17, Bethesda, Maryland.

Youngs, W. D., and Heimbuch, D.G. 1982. Another consideration of the morphoedaphic index. Trans. Am. Fish. Soc. 111: 151-153.

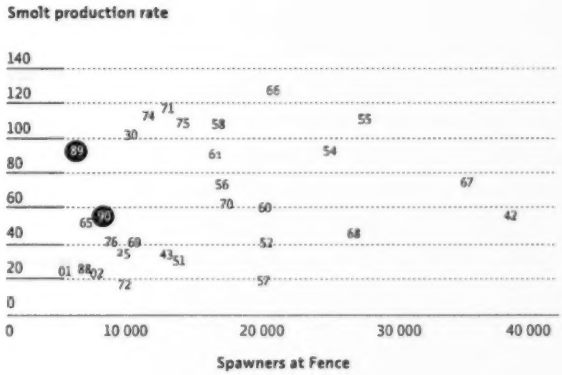
Zubel, M. 2000. Groundwater conditions of the Columbia Valley Aquifer, Cultus Lake, British Columbia. Ministry of Environment, Lands and Parks, Water Management, Lower Mainland Region. Surrey. 98 p.

ANNEXES

Annex 1 | Freshwater Productivity

The recent decline in the number of smolts produced from Cultus Lake (COSEWIC 2003) has prompted an update and review of available smolt production data. Annex Figure 1 shows the complete Cultus Lake smolt production data with the following notes:

- The 1926-42 broods affected by hatchery operations or predator control are excluded;
- The 1988-1991 spawner estimates were adjusted upward to account for a particularly short period of operation of the adult counting fence;
- The 1989-1990 broods affected by predator control are included but highlighted in red;
- The 1999-2000 broods with very high PSM are excluded (about 5 smolts/spawner in each year);
- The 2001 brood was probably affected by PSM, but no direct estimates are available;
- The 2002 brood suffered a 13% loss due to PSM which is not accounted for in the figure; smolts/effective spawner would be correspondingly higher;
- For clarity the figure is cut off at 40,000 spawners; the two broods with higher escapement are not shown, but are included in the calculation of the averages; and
- Age data are not included in the most recent smolt runs, which will introduce small errors.



Annex Figure 1. Relation between smolts/spawner and spawners for Cultus sockeye.

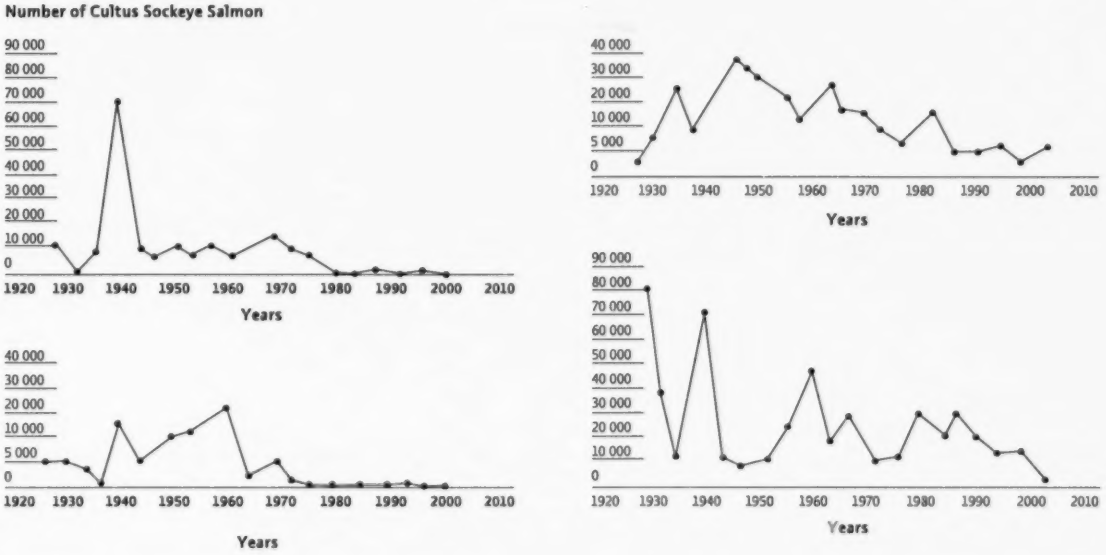
Points appear as brood years. ■ indicates years affected by pikeminnow removal program that removed an estimated 10-20% of the population. See text for other notes. Courtesy: DFO

Visual examination of these data suggests two groupings: at spawner abundances greater than 7,000 spawners the smolt production rate is variable but has an arithmetic mean of 68 smolts/spawner (range 16-125); and at abundances less than 7,000 the production rate is 32 smolts/spawner (excluding the 2 predator control years) or 41 smolts/spawner (including the predator control years).

While the low-productivity data cluster includes some recent years in which unknown rates of PSM may have contributed to low smolts/spawner, it is noteworthy that small broods from as early as 1925 have experienced low productivity. The available data thus do not support the hypothesis of a recent declining trend in productivity associated with habitat or ecosystem changes, but rather suggest a consistent pattern of salmon survival. Alternatively, the apparent pattern in the data could be simply due to chance, given the inherent high variability in the data.

A common explanation for the observation of low survival when abundance is low is depensatory predation, where the predator population consumes a relatively constant number of prey even when prey abundance is low. This phenomenon has been observed in salmon spawning streams where emigrating smolts were preyed upon by large fish that aggregated at the stream during the migration (Peterman and Gatto 1978).

If the hypothesis of depensatory mortality is confirmed (by the collection of more monitoring data), then the Cultus sockeye salmon population may have limited potential for rebuilding or sustaining exploitation when abundance is below the threshold of 7,000 spawners. Indeed, analysis of the trajectories of the 4 cycle lines (Annex 2) does suggest that recovery from below 5,000 spawners is difficult. As an illustration of the problem, consider the case of a brood producing 30 smolts/spawner, with a 5% smolt-adult survival, 15% exploitation rate and 15% prespawning mortality. The expected rate of population growth is only 8% per generation compared to 116% if the smolt production is 60 smolts/spawner. A small increase in any of these mortality factors could lead to population decline if smolt production rates remain low.



Annex Figure 2. Time series of the 4 cycle lines of Cultus sockeye salmon, labelled in the text as the 1999-2003 cycle lines.

Most broods between 1926 and 1942 were affected by either hatchery operations or predator control. Courtesy: DFO

Objective 4 refers to the setting of a target level of abundance that will support ecosystem function and sustainable use. The ultimate reference point is the theoretical maximum production that can be achieved by a stock under ideal conditions with no harvest – a number that can be estimated using stock recruit curves and methods based on freshwater habitat capacity at various life history stages, including spawning ground capacity and lake rearing capacity. Below this theoretical level are other potential benchmarks, four of which are described below. Their relative merits must be evaluated in the context of broader societal objectives.

Lake productive capacity as a benchmark (the photosynthetic rate model)

Predicting the production capacity for fish in a particular body of water is an important objective of North American freshwater fisheries management (see Leach *et al.* 1987 for a review). It has relevance for management of recreational and commercial fisheries (sustainable yield) and for enhancement (the amount that recruitment to a lake can be increased). Biological reference points are most commonly based on fishing mortality rates or stock abundance derived from stock-recruit relationships (Mace and Sissenwine 1993, Mace 1994). In many cases, however (*e.g.*, B.C. steelhead trout), the stock-recruit relationship is either poorly defined or not known (Johnston *et al.* 2002). In the case of steelhead trout, these authors show how the β parameter (carrying capacity or the asymptotic number of smolts produced at very large spawner numbers) in a Beverton-Holt stock recruit model is closely related to estimates of habitat capacity in moderately productive steelhead trout streams. In practical terms, however, this correlation has not been very useful for developing milestones or reference points.

Productive capacity estimates for Cultus sockeye that use stock-recruit relationships are also unreliable. The spawning ground capacity of the lake has not been determined and cannot, therefore, be used to estimate productive capacity. However, there have been attempts to develop empirical relationships between lake productivity and fish yield, and estimates of juvenile lake rearing habitat have been made using a model based on photosynthetic rate (the PR model; Hume *et al.* 1996, Shortreed *et al.* 2000).

Since a direct measure of productivity (*i.e.*, photosynthetic rate) is not usually available, investigators use a number of other limnological variables as surrogates for PR. These include mean depth and total dissolved solids (Ryder 1965), summer average chlorophyll concentration (Oglesby 1977; Jones and Hoyer 1982), lake area (Youngs and Heimbuch 1982), euphotic zone depth (Koenings and Burkett 1987), and total phosphorus concentration (Stockner 1987; Downing *et al.* 1990).

Fee *et al.* (1985) and Downing *et al.* (1990) reported that PR measurements were positively correlated with fish yield. Further, Downing *et al.* (1990) found that PR was more closely correlated with fish yield than with other variables commonly used as indices of lake productivity (chlorophyll, total phosphorus). Shortreed *et al.* (2000) investigated the relationship between lake area and primary production to the maximum observed juvenile sockeye biomass in Alaskan and B.C. lakes. They found that lake area alone explained 65% (r^2) of the variation in sockeye biomass. Including primary production as total seasonal carbon production (PR_{total}, tonnes C/lake) improved this relationship considerably, and explained 91% of the variation. Annual variability in PR_{total} for a wide range of B.C. lakes averaged ±8% 2SE.

The PR model (Hume *et al.* 1996) was derived from the euphotic volume (EV) model (Koenings and Burkett 1987; Koenings and Kyle 1997) which was itself developed using data from a number of Alaskan lakes. Both models provide predictions of optimum escapement, optimum spring fry recruitment and maximum smolt output. The EV model uses euphotic zone depth as a surrogate for productivity. In B.C. lakes, euphotic zone depth is not an appropriate surrogate for productivity (Hume *et al.* 1996). The PR model uses a direct measure of lake productivity (photosynthetic rate) and so is applicable to a wider range of lakes. Shortreed *et al.* (2000, 2001) revised the PR model, tested the model predictions, discussed model assumptions, and presented model estimates for many B.C. lakes. These estimates have been used as the basis for estimating sockeye stock status in most rearing lakes in the Fraser, and Skeena watersheds (Cox-Rogers *et al.* 2003, Hume *et al.* 1996, Shortreed *et al.* 2000, 2001).

The relationship between adult spawners and smolts used in the PR model is equivalent to 54.2 smolts per adult and is based on experimental stocking experiments (Koenings and Burkett 1987). Smolt size at maximum smolt biomass is assumed to be 4.5 g, which is the average size of smolts at higher spawner densities. These values are used to produce the current estimate for Cultus Lake.

PR model predictions are based on the capacity of the lake to rear juvenile sockeye and compensate for competition from other mid-water fish, but not for other factors such as spawning ground limitation or predation. Shortreed and Hume (2004 pers. comm.) estimated the productive capacity of Cultus Lake from monthly limnological samples through two growing seasons from April 2001 to March 2003. They adjusted the PR model for the diversion of productive capacity into limnetic fish other than sockeye (see Cox-Rogers *et al.* 2003) using midwater trawl (species composition and size) and hydroacoustic target strength data to estimate the biomass

of non-sockeye species. These species, which include pygmy sculpins, threespine stickleback, kokanee and redside shiner, comprise about 9% of the total limnetic biomass. Assuming that these fish are direct competitors of sockeye, they used this proportion to reduce the primary production available to sockeye.

In Cultus Lake, total seasonal carbon production (PR_{total}) was 447 tonnes in 2001 and 535 tonnes in 2002.

The predicted optimum escapement resulting from these estimates was 83,000 in 2001 and 100,000 in 2002 (average: 92,000). *After adjustment for non-sockeye competitors, predicted optimum escapement was reduced to 75,000 in 2001 and 91,000 in 2002 (mean: 83,000).*

S_{MSY} as a benchmark

S_{MSY} is the spawner biomass or abundance that will yield the maximum sustainable yield (MSY) over the long term. For most populations, S_{MSY} will be a fraction (often 0.3-0.6) of the un-fished equilibrium biomass. S_{MSY} is usually estimated from population models or, in the case of salmon, from a stock-recruit relationship. Less exact estimates of S_{MSY} may be derived from habitat capacity or from other surrogates for productive capacity. *For Cultus sockeye, S_{MSY} is 32,000 successful spawners.*

Fisheries managers use S_{MSY} as a benchmark or reference point to evaluate the status of stocks and establish rules for management actions (Richards and Maguire 1998). Fishery management policies in various jurisdictions use S_{MSY} in different ways once the status of the stock has been established, and provide examples of how S_{MSY} might be used for Cultus sockeye salmon.

One way is to consider S_{MSY} a target reference point (TRP), a desired state at which the stock should exist or exceed. In this case, fishing mortality rates are chosen to maintain the stock at or above S_{MSY}. However, because fisheries can overshoot their targets and cause stocks to fall below S_{MSY}, some researchers have suggested that S_{MSY} should instead represent a limit reference point (LRP) below which the stock should rarely go, and that would trigger drastic management actions if it did (Caddy and Mahon 1995). Between the LRP and TRP is an area of intermediate management actions usually devised to maintain or increase the abundance of the stock to the TRP over a specified time frame (Restrepo and Powers 1999). Using S_{MSY} as a limit reference point (LRP) signifies a greater level of conservation concern for stocks when they fall below this point. For example, the North Atlantic Salmon Conservation Organization (NASCO) recognizes S_{MSY} as a Conservation Limit (see http://www.nasco.int/pdf/nasco_res_decision.pdf) for the NASCO definition of this LRP).[3]

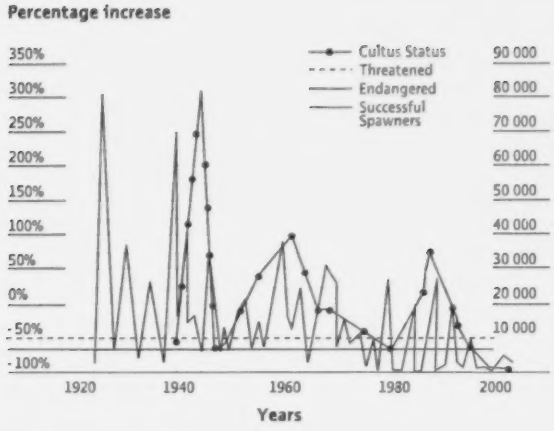
The *Sustainable Fisheries Act of the US* provides an example of S_{MSY} as a benchmark for stock rebuilding. The Act specifies that a stock below S_{MSY} is considered over-fished and a plan must be articulated for its recovery. The management plan will have a harvest control scheme that will result in the rebuilding of the stock to S_{MSY} in 10 years, if biologically feasible, or longer if the biology of the population constrains rebuilding. In the case of mixed-stock fisheries, it is recognized that some populations will likely be over-fished when more productive stocks are the focus of the harvest. The Act states that MSY must be estimated for each stock, but over- fishing (defined as an exploitation rate that "*jeopardizes the capacity of the stock to produce MSY on a continuing basis*") can be permitted if the following conditions are met (paraphrased from SFA s600.310(d)(6):

- The overall benefits from over fishing some stocks within the mixed-stock fishery are greater than would be achieved from a lower level of harvest that would not result in over-fishing;
- There is no other means to achieve similar benefits from the fishery without over-fishing (*e.g.*, through the modification of fishing practices, techniques or equipment);
- The resulting over fishing will not result in the stock becoming threatened so that Endangered Species Act protection is required.

In a final example, the abundance that allows the population to return to S_{MSY} in one generation or more is a limit reference point used for the management of steelhead trout in British Columbia. *For Cultus sockeye, this number is 10,300 successful spawners.*

The exploitation rate at which S_{MSY} is achieved (56%) can be more precisely estimated than the actual spawner abundance at S_{MSY}. In addition, ER values can be more easily meshed with broader based policy objectives developed by Government, stakeholders and interested parties. Consequently, Cultus sockeye population milestones could be based on $ER(S_{MSY})$, or some fraction of $ER(S_{MSY})$ for the Cultus population.

[3] Conservation limits demarcate the undesirable spawning stock level at which recruitment would begin to decline significantly. The level cannot be used in management without also defining the acceptable probability (e.g., proportion of years) when the stock may be permitted to fall below the conservation limit. Currently NASCO and ICES define the conservation limit as the spawning stock level that produces maximum sustainable yield (formerly referred to as Minimum Biologically Acceptable Level or a Spawning Target).



* time frames calculated using 1 generation average data

Annex Figure 3. Population increase/decline of Cultus Lake sockeye salmon over three generations (12 years)*. Courtesy: DFO

* time frames calculated using 1 generation average data

Historic abundance as a benchmark

Historic spawner abundance during periods of relatively low exploitation has been used to set long term management goals by agencies in Alaska, Washington and Oregon (Knudsen 1999). While the Cultus population has been exploited at relatively high levels in most years since 1953 (COSEWIC 2003), reconstructions for earlier periods (1892-1944) suggest that exploitation rates rarely exceeded 50% (Gilhousen 1992). The average spawner abundance between 1925 and 1952, corrected for return years influenced by early enhancement interventions (1930, 1932-33, 1936-37) and predator control projects (1938-40) could, therefore, serve as a target level of abundance for the Cultus population. The average spawner population during this era was about 20,000, with decadal averages of 16-25,000. This era represents a long period of stable abundance during which dramatic declines (to 10,000 spawners or less) were rare. *Consequently, the 20,000 average spawner population size during the era of lower exploitation could serve as a long term goal for Cultus sockeye.*

In conjunction with historic abundance, insights can be gained by evaluating earlier periods of population decline that would have triggered designations of Endangered had IUCN criteria been available or applied at the time (Annex Figure 3). There were three such periods: the 1938-49 decline in generational abundance from 36,000 to 15,000; the 1965-76 decline from 15,000 to 5,000; and the further decline to 2,000 during the current evaluation period. The earliest decline can be generally discounted because the initial high abundances likely resulted from short term increases in freshwater productivity resulting from predator removals.

The 1965-76 decline is more significant. Its principal cause, namely over-fishing following the construction of the Weaver spawning channel, is among the reasons cited by COSEWIC for the current status of the population. It was during this period that the population fell below the threshold of spawner abundance associated with dramatically reduced smolt production from the lake (see *Biological Limiting Factors*). Significantly, the population has since been unable to recover to previous levels of abundance (rather than true recovery, the improved status in the figure reflects the movement of the 12-year sliding assessment period beyond the high initial abundances of the 1960s). The average population levels of the mid-1960s had been stable for several decades, while those of the late 1970s have proven to be unsustainable, allowing the population to continue declining to levels where extinction is now a real threat. Consequently, *the average population size at the start of this earlier decline, 15,000 (one generation average) to 19,000 (two generation average), could serve as a long term goal for Cultus sockeye. Given that the population abundances of the lower exploitation era were maintained in the 1950s and into the 1960s, the goal could be placed in the context of the full data set by adopting the 1925-1968 average, namely 20,000, as a long term goal.*

Ecosystem function as a benchmark

Ecological relationships place constraints on the planning, execution and evaluation of sustainable harvesting. Recovery of Cultus sockeye should aim to maintain ecological relationships among species, within the bounds of natural fluctuations, and to minimize the risk of changes to those relationships that are difficult or impossible to reverse.

While the abundance at which ecosystem disruption occurs could be considered as a milestone, there is presently great difficulty in quantifying not only the ecological relationships that involve Cultus sockeye, but also the level of abundance at which these relationships are unacceptably jeopardized. What we know about the ecological relationships of Cultus sockeye is discussed earlier (see *Ecological Role*) and includes:

- Carcasses are probably directly available to primary producers in the lake, and could result in increased periphyton productivity with benefits to benthic invertebrates and littoral fish species. Such nutrients, however, would probably cause detectable increases in productivity only at higher escapements;
- Many bird and animal species at Cultus Lake feed directly on salmon carcasses or eggs (*e.g.*, eagle, gull, some waterfowl, Steller's jay, raccoon, mink, and otter);

- Fish species other than sockeye may feed directly on carcass flesh or salmon eggs; and
- Juvenile sockeye represent a food supply for a number of other fish species such as juvenile coho, cutthroat, rainbow, sculpins, and pikeminnow, so that sockeye may function to regulate the abundance of other species in the ecosystem. These all consider sockeye as a source of prey nutrients; sockeye are also predators and competitors, and may function to regulate abundance of other species in the ecosystem

At what level of spawner abundance are the above relationships affected? Is there a level of abundance that can be quantitatively linked to ecosystem disruption? At present, neither of these questions can be answered without further scientific study. DFO's *Draft Policy on Fishery on Forage Species* may provide some relevant guidelines for maintenance of ecosystem relationships in fisheries.

Annex 3 The Cultus Sockeye Captive Breeding Project

The captive breeding project began on an *ad hoc* basis in 2000 when very few spawners returned to the Sweltzer Creek fence and those that did were in very poor condition. Five females and ten males were captured and the survivors were spawned (PSM was very high), with the progeny incubated and reared at the Cultus Lake Laboratory over the next 18 months. Because the small number of spawners limited genetic diversity, all of these fish were marked with an adipose clip and released as smolts; they were replaced by wild smolts emigrating through Sweltzer in the spring of 2002. These fish were moved to the Chilliwack River Hatchery for disease screening and parasite removal (they suffered high mortality from parasitic copepods), and subsequently to the Rosewall Creek Hatchery on Vancouver Island. Eighty-nine of these fish matured in 2003 and 205 in 2004, producing 46,000 and 632,000 fertilized eggs respectively.

A small number of adults were captured in 2001, again with high PSM. They were incubated and initially reared at Cultus Lake, then transferred to the Chilliwack River Hatchery for disease screening and parasite removal and finally to the Rosewall Creek Hatchery on Vancouver Island for rearing to maturity. Juveniles that were surplus to the requirements of the captive breeding project were released into Cultus Lake as fry in the fall of 2002 and as smolts in the spring of 2003. Ninety percent of the released fish had their adipose fin clipped. Also in the spring of 2003, 881wild smolts were retained for captive breeding to broaden the genetic diversity of the captive population. These fish were moved to the Inch Creek Hatchery for disease screening and parasite removal (there was very little mortality thanks to lessons learned with the 2000 brood year smolts) and subsequently to the Rosewall Creek Hatchery. Over 500 of these fish matured in 2004, producing nearly 700,000 fertilized eggs.

In the fall of 2002, the project was redesigned, with larger brood stock targets to permit testing various methods to reduce PSM and maximize subsequent survivals. The egg-take used a matrix spawning technique to produce almost 500 separate mating families and over 400,000 eggs. Both pre-spawn and incubation mortality were much lower than in the previous two years. Ten eggs selected from each mating were retained in the captive breeding project; the remainder (227,000 4-g fry) were incubated and reared at the Inch Creek Hatchery before release into Cultus Lake as marked fry in October.

Almost 350,000 fry were calcein-marked and released into Cultus Lake in 2004. In the fall of 2003, another large egg-take permitted about 500 mating families.

Annex 4 | Cultus Sockeye Recovery Team members

Bradford, Michael

Research Scientist, DFO. Simon Fraser University, 8888 University Drive, Burnaby, BC, V5A 1S6. Tel. 604-666-7912, Fax. 604-666-1995. bradfordm@pac.dfo-mpo.gc.ca

Clark, Bruce

Habitat Biologist, DFO. 100 Annacis Parkway, Unit 3, Delta, BC, V3M 6A2. Tel. 604-666-6140, Fax. 604-666-6627. clarkb@pac.dfo-mpo.gc.ca

Connolly, Ken

Manager, Area E Gillnetters Association. 11498 Barclay Street, Maple Ridge, BC, V2X 1S6. Tel. 604-465-7651, Fax 604-465-7651. kconnolly@telus.net

Folkes, Michael

Salmon Assessment Biologist, DFO. Pacific Biological Station, 3190 Hammond Bay Rd, Nanaimo, BC, V9R 5K6. Tel. 250-756-7264, Fax. 250-756-7053. folkesm@pac.dfo-mpo.gc.ca

Gable, Jim

Management Biologist, Pacific Salmon Commission. 600-1155 Robson St, Vancouver, BC, V6E 1B5. Tel. 604-684-8081, Fax 604-666-8616. gable@psc.org

Gazey, Bill

Fisheries modeler and analyst, W.J. Gazey Research, 1214 Camas Court, Victoria, BC, V8X 4R1. Tel. 250-727-6992, Fax. 250-727-0601. Bill@Gazey.com

Grout, Jeff

Resource Management Biologist, DFO. 100 Annacis Parkway, Unit 3, Delta, BC, V3M 6A2. Tel. 604-666-8616, Fax. 604-666-7112. groutj@pac.dfo-mpo.gc.ca

Hinch, Scott

Assistant Professor Institute for Resources, UBC, 1933 West Mall Annex, Vancouver, B.C. V6T 1Z2. Tel. 604-822-9377, Fax 604-822-5357. shinch@interchg.ubc.ca

Johnson, Mark

Area Community Advisor, DFO. Cultus Lake Laboratory, 4222 Columbia Valley Highway, Cultus Lake, B.C. V2R 5B6. Tel. 604-824-4715. Fax. 604-858-3757, johnsonm@pac.dfo-mpo.gc.ca

Kelly, Doug

Chief, Soowahlie Band. 4070 Soowahlie Road, Cultus Lake, BC, V2R 4Y2. Tel. 604-858-4603, Fax. 604-858-2350. dckelly@uniserve.com

Kwak, Frank

VP Fraser Valley Salmon Society, Director B.C Federation of Drift Fishers. 2302-8485 Young Rd., Chilliwack, BC, V2P 7Y7. Tel. 604-702-8083. frankkwak@shaw.ca

MacKinlay, Don

Enhancement Biologist, DFO. 401 Burrard Street, Vancouver, BC, V6C 3S4. Tel. 604-666-3520. mackinlayd@pac.dfo-mpo.gc.ca

Morley, Rob

VP, Canadian Fishing Company, Foot of Gore Avenue, Vancouver, BC, V6A 2Y7. Tel. 604-681-0211, Fax. 604-681-5916. Rob.Morley@canfisco.com

Pestes, Linsey

Masters Student, SFU. 8888 University Drive, Burnaby, BC. V5A 1S6. Tel. 604-251-2022. lpestes@sfu.ca.

Roberts, Jim

Fisheries Biologist, WLAP. 10470 152 St. Surrey BC, V3R 0Y3. Tel. 604-582-5303, Cell 604-868-5220, Fax 604-930-7119. jim.roberts@gems9.gov.bc.ca

Schubert, Neil (Chair)

Area Chief of Stock Assessment, DFO. 100 Annacis Parkway, Unit 3, Delta, B.C, V3M 6A2. Tel. 604-666-8452, Fax. 604-666-7112. schubertn@pac.dfo-mpo.gc.ca

Shortreed, Ken

Head, Lake Assessment Program, DFO. Cultus Lake Laboratory, 4222 Columbia Valley Highway, Cultus Lake, B.C. V2R 5B6. Tel. 604-824-4707. Fax. 604-858-3757, shortreedk@pac.dfo-mpo.gc.ca

Victor, Ernie

Fisheries Manager, Sto:lo Nation, Bldg 2, 7201 Vedder Rd, Chilliwack, B.C. V2R 1A5, Tel. 604-858-7557, Fax 604-858-9959. Ernie.victor@sto:lonation.bc.ca

Wilson, Doug

Parks Manager, Fraser Valley Regional District, 8430 Cessna Drive, Chilliwack, BC, V2P 7K4. Tel. 604-702-5077, Fax. 604-792-9684. Dwilson@fvrd.bc.ca

Wood, Chris

Section Head, Conservation Biology, Pacific Region, DFO. Pacific Biological Station, 3190 Hammond Bay Rd, Nanaimo, BC, V9R 5K6. Tel. 250-756-7140, Fax. 250-756-7053. woodc@pac.dfo-mpo.gc.ca

The Recovery Team

In November 2003, DFO engaged a Cultus Sockeye Recovery Team (CSRT) to work cooperatively in the development of this conservation strategy. The CSRT membership included participants from First Nations, the province of British Columbia, academia, industry, local government as well as biologists and community members. Each team member brought important technical expertise or knowledge of Cultus sockeye to the development of the recovery strategy. Soowahlie and Sto:lo First Nations members provided local knowledge and ensured that recovery planning information was shared with their communities.

Technical workshop

On April 29th 2004, DFO held a technical workshop by invitation to engage a broader group of experts and participants to review early drafts of the conservation strategies for the Cultus and Sakinaw sockeye and interior Fraser coho populations. The intent of the workshop was to:

1. Share knowledge and information with the communities, groups and individuals likely to play a key role in conservation or to be impacted by conservation actions;
2. Receive technical advice on the goals, objectives and approaches in the draft strategies. This advice is summarized by Marmorek *et al.* (2004)
3. Engage participants in the conservation process.

Advice on the Cultus sockeye recovery strategy included the need for sensitivity analyses of the minimum abundance and production criteria (e.g., marine survival, changes in spawner-recruit relationships, extent of by-catch), rationales for specific minimum abundance levels, and estimates of the risks of falling below them over different time periods. Clear de-listing criteria were considered important.

Habitat issues were also of concern: protecting, rehabilitating and maintaining water quantity (especially water flow and levels); defining and specifying important habitat; understanding estuarine and early ocean survivals; and using an adaptive management approach, with carefully designed monitoring of various life history stages to assess the effectiveness of implemented actions. The need for outreach and partnerships to sustain the conservation efforts was also stressed.

Community consultations

In October and November 2004, DFO conducted seven information sessions on the draft strategy to solicit feedback from First Nations and other stakeholders. DFO announced the consultation process in early October 2004, with a press release throughout B.C. Invitations were mailed to 197 First Nations, First Nations organizations, tribal councils and fisheries commissions, and to more than 5,000 stakeholders, including all commercially licensed fishermen, recreational fishing and conservation organizations, local governments and stewardship groups. Advertisements were placed in local newspapers that serve the communities in which the sessions were held. In addition, a number of follow-up telephone calls, emails, and personal communications were made by DFO to encourage participation.

Two-day session were held in Prince Rupert, Victoria, Nanaimo, Port Hardy, Campbell River, Vancouver, and Chilliwack. The first day was an information session for First Nations and an evening open house for the public where information on the strategy was presented in posters and fact sheets. Recovery Team members were present to answer questions and receive comments from the public. The second day was a stakeholder meeting where DFO staff and Team members presented key elements from the draft strategy. DFO developed and distributed a discussion guide consisting of questions on each of these key elements, which led to a facilitated discussion generating valuable comments from participants.

Representatives from the following organizations attended and provided input at the workshops: Yale First Nation, Cheam First Nation, Soowahlie First Nation, Seabird First Nation, Gwasala-nakwaxda'xw First Nation, Kwakiutl First nation, Gwawaenuk Tribe, Cape Mudge First Nation, A-Tlegay Fisheries, Musqueam Fisheries, Heiltsuk Tribal Council, Tsartlip First Nation, Tsawout First Nation, Metlakatla First Nation, Gitanyow Fisheries, Kitkatla First Nations, Haisla Fisheries, Hartley Bay First Nations, Kitsumkalum Nation, Lake Babine Nation, Wet'suwet'en Nation, Fraser Valley Regional District, Chilliwack Fish and Game, Central Valley Naturalists, Fraser Valley Angling Guides Association, Elk Creek Conservation Coalition, City of Chilliwack, Chilliwack High School, District of Mission, Fraser River Sturgeon Conservation Society, BC Federation of Drift Fishers, Pacific Fisheries Resource Conservation Council, Vancouver Aquarium, UFAWU, Fraser River Port Authority, Canadian Parks and Wilderness, David Suzuki Foundation, Northern Halibut Producers Association, Village of Tahsis, North Coast Troller, CRTV, Hook and Line Groudfish Association, District of Port Hardy, Qualican Rivers Resorts, Living Oceans Society, SFAB, Area G Trollers, Hesquiat Tribe, Marine Conservation Council, Area C and E Gillnet, Sierra Club, Georgia Strait Alliance, Ahousat Nation, Sport Fishing Defence Alliance, T. Buck Suzuki Foundation, Royal Pride, Christau, Oona River Resources Association, World Wildlife Foundation, and Golden Chalice.

Many participants viewed the draft strategy as well thought out and comprehensive, in part because Cultus sockeye have been studied for so long and are well understood. Participants recommended that the strategy address the issues of groundwater extraction, contamination by septic tanks, pesticide use, recreational boating and related hydrocarbon pollution, impervious surfaces and other human-caused impacts. Commercial fishermen in particular noted the importance of assessing activities other than fishing as principal causes of this stock's decline. A summary of feedback from the consultations is available at http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/consultation2004/main_e.htm

Consultation input has been incorporated into the strategy wherever possible. For example, concerns relating to pollution and habitat degradation of the lake have been addressed in *Threats to Population Viability and Recovery*, which indicates that freshwater habitat degradation is not thought to be the main cause of the population's recent decline. At the same time, the Recovery Team has noted in *Knowledge Gaps* that the impacts of habitat change are not well-known and that there is a need for research to determine the effects of recreational boating and land use activities. Furthermore, the Team has clarified, in *Approaches to Meeting Conservation Objectives*, that harvest is in fact possible during recovery, a key concern of many of the stakeholders participating in the workshops.

Other meetings

The CSRT has also engaged the local community and other interested stakeholders in additional consultations over several years to provide an opportunity for information exchange prior to and during the development of the strategy. These meetings included the following:

Date:	November 14, 2001
Group:	Public Meeting;
Location:	Cultus Lake, B.C.
Date:	July 2, 2003
Group:	Public Meeting
Location:	Cultus Lake, B.C.
Date:	June 4, 2004
Group:	Commercial Salmon Advisory Board
Location:	Vancouver, B.C.
Date:	June 8, 2004
Group:	Lower Fraser Aquatic Resource Management Forum
Location:	Chilliwack, B.C.